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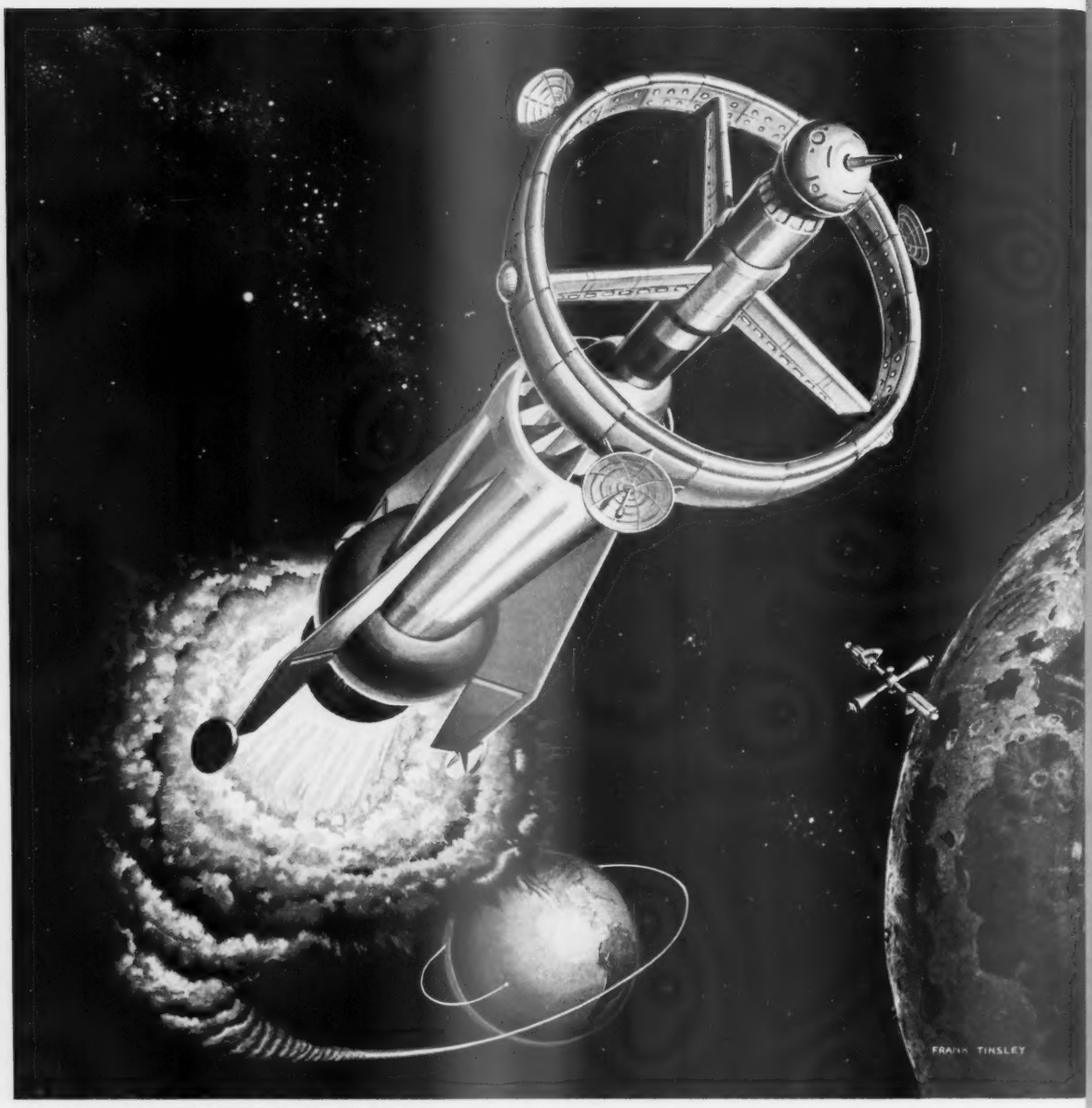
EDITORIAL: *A New VGM* . . . p. 27

FEBRUARY / 1960



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The Atomic Pulse Rocket could transport payload to the Moon at $6.74 per lb., less than one quarter the prevailing air freight charges over equivalent distance

A similar project is past the pilot study stage in the Defense Department

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AERO/SPACE ENGINEERING

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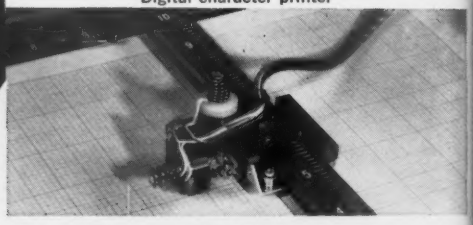

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IAS BULLETINS AND LATE NEWS...

February 1960

SIMON RAMO, EXEC. VICE PRESIDENT, THOMPSON RAMO WOOLDRIDGE INC., will be dinner speaker at the Manned Space Stations Symposium on April 20 in Los Angeles.

THE HONORS NIGHT DINNER was the occasion for the presentation of Honorary Fellowships to Elmer A. Sperry, Jr. and E. T. Jones. Named Fellows were J. V. Charyk, Alfred Eggers, Jr., V.Admiral J.T. Hayward, Lester Lees, C.O. Lin, E.J. Manganiello, H. J. van der Maas, and Lysle Wood. Other awards presented by the IAS were the Louis W. Hill Space Transportation Award to James A. Van Allen; The John Jeffries Award to Brig. Gen. Don Flickinger; The Robert Losey Award to Herbert Riehl; The Sylvanus Albert Reed Award to Karel J. Bossart; and The Lawrence Sperry Award to James E. McCune. IAS Minta Martin National Student Awards went to William Rae, Ronald Stearman, E. Brian Pritchard, and Charlie M. Jackson, Jr.

IAS OFFICERS FOR 1960 AND NEW COUNCIL MEMBERS were elected at the Annual Meeting on January 27. Vice Presidents are Col. Paul H. Dane, Harold Luskin, and Charles Tilgner, Jr. Victor E. Carbonara is Treasurer. New Council Members are Peter Altman, John S. Attinello, Milton U. Clauser, Preston E. Dickson, Hubert Flomenhoft, Welko Gasich, Donald Germeraad, Nicholas J. Hoff, Lawrence Levy, Axel Mattson, Clyde R. Murtaugh, Vernon Outman, and Yusuf A. Yoler.

Detailed information and pictures on award winners, officers, and new Council members will appear in next month's issue of Aero/Space Engineering.

A ONE-YEAR COURSE IN EXPERIMENTAL AERODYNAMICS is being offered, tuition free, to graduate engineers and scientists. For information and applications (due March 19) write: The Director, Training Center for Experimental Aerodynamics, 72, chaussee de Waterloo, Rhode-Saint-Genese, Belgium.

THE FUTURE OF MANNED MILITARY AIRCRAFT is the subject of a recently scheduled meeting to be held in San Diego, Calif., August 1-3.

EDITOR'S NOTEBOOK: Aero/Space Engineering's series of electronics articles, announced last month, will make its debut with "A Comparison of Experimental Performance of Electric Regenerative Packed Bed Heat Sinks with Analytical Data" in the June issue. Authors Saltzman, Plizak, Tomko, and Nycum will include a discussion on the performance of thermal barriers as shock and vibration isolators, showing that certain types of thermal barrier materials have shock and vibration isolation characteristics superior to requirements called out in present specifications. Subsequent articles will take up packed regenerator design, performance of regenerators, cooling by chemical kinetics and catalysis, and an analytical cooling specification.

SECTION MEETINGS CALENDAR*

Feb. 9 Cleveland-Akron: Joint Dinner Meeting with ARS, Secret, NASA Lewis Res. Center, "Aero Recovery of Parachute Borne Payloads by Fixed or Rotating Wing Aircraft", Capt. R. C. Fruge, Jr., USAF.

Feb. 9 Los Angeles: Specialists Meeting, IAS Bldg., 8 p.m., "Development of a Low Thermal Conductivity Alloy for Brazing Stainless Steel Honeycomb Sandwich", Carl J. Muser, Sr. Research Engr., North American Aviation.

Feb. 9 Washington: Dinner Meeting, Occidental Restaurant, 7 p.m., "Impact of Advances in Technology on the Aerospace Industry", J. R. Clark, Gen Mgr., Astronautics Div., Chance Vought Aircraft, Inc.

Green Sheet (Con't.)

Feb. 10 Niagara Frontier: Dinner Meeting, Cornell Aero. Lab. Cafeteria, 7:30 p.m., "Aircraft Industry", Harvey Gaylord, President, Bell Aircraft Corp.

Feb. 11 San Diego: Space Science Lecture, IAS Bldg., 7:30 p.m., "Chemical Kinetics and Reaction Rates", O. Meyers.

Feb. 15 Wichita: Joint Meeting with SAE & ARS, Innes Tea Room, 6:30 p.m., Speaker will be Dr. Richard W. Porter, Consultant, General Electric Co.

Feb. 16 San Diego: Space Science Lecture, IAS Bldg., 7:30 p.m., "Erosion of Satellites and Meteors", D. B. Medved.

Feb. 17 Texas: Technical Meeting, Engrg. Auditorium, Arlington State Coll., 8 p.m., "Development of the Atlas ICBM", C. S. Ames, Chief Project Engr., Convair Astronautics.

Feb. 18 Los Angeles: Dinner Meeting, Secret, IAS Bldg., 6 p.m., "Observations on the Space Age", L. Eugene Root, Vice Pres., Lockheed Aircraft Corp.

Feb. 23 Los Angeles: Specialists Meeting, IAS Bldg., 8 p.m., "Steady Two-Dimensional Flow About Hydrofoils with Gas Exhaust", Andrew G. Fabula, NOTS.

Feb. 24 St. Louis: Technical Meeting, McDonnell Aircraft Auditorium, 8 p.m., "Space Systems and Satellites", Col. W. G. O'Brien, USAF, Chief, Space Systems Education Div., AFBMD.

Feb. 25 Baltimore: Dinner Meeting, Westinghouse Air Arm Div. Cafeteria, 7 p.m., "High Altitude Balloon Research", Malcolm D. Ross.

Feb. 25 Hampton Roads: Technical Meeting, Newport News High School Auditorium, 8 p.m., "Manned Interplanetary Flight", Krafft Ehricke, Asst. to the Chief Engineer, Convair Astronautics.

Feb. 25 Kansas City: Joint Dinner Meeting with SAE, Wishbone Restaurant, 7 p.m., "Lunar Explorations", Dr. Robert Jastrow, Chief, Theoretical Div., Goddard Space Flight Center, NASA.

Feb. 25 San Diego: Space Science Lecture, IAS Bldg., 7:30 p.m., "Economic Feasibility of Recoverable Boosters—Airbreathing and Rocket", P. R. Shipps and D. Jones.

Mar. 1 San Diego: Space Science Lecture, IAS Bldg., 7:30 p.m., "Vehicles for Interplanetary Flight", F. A. Ford.

Mar. 8 Los Angeles: Specialists Meeting, IAS Bldg., 8 p.m., "Importance of Panel Flutter in Design of Light Weight Structures", Bert Fung.

*Items for this section accepted up to seven working days before end of the month.

INTERNATIONAL, NATIONAL, AND JOINT MEETINGS CALENDAR

Mar. 10–11	Flight Propulsion Meeting (Classified), Cleveland, Ohio.
Apr. 20–22	Symposium on Manned Space Stations (cosponsored by NASA and The RAND Corp.), Ambassador Hotel, Los Angeles, Calif.
May 2–4	IRE Aeronautical Electronics Conference (Participation by Dayton Section of IAS), Dayton, Ohio.
May 23–25	National Telemetering Conference (cosponsored by IAS, ISA, ARS and AIEE), Hotel Miramar, Santa Monica, Calif.
May 25–27	Specialists Meeting, Guidance of Aerospace Vehicles, Boston, Mass.
June 28–Jul. 1	Summer Meeting, Ambassador Hotel, Los Angeles, Calif.
Aug. 1–3	Meeting on Future of Manned Military Aircraft, San Diego, Calif.
Sept. 12–16	2nd International Congress, International Council of the Aeronautical Sciences, Zurich, Switzerland.
Oct. 3–5	Midwestern Conference on Air Logistics, Tulsa, Okla.
Oct. 17–18	CAI/IAS Joint Meeting, Queen Elizabeth Hotel, Montreal, Canada.
Oct. 20–21	Symposium on Hypervelocity Techniques, Denver, Colorado.
Dec. 17	Wright Brothers Lecture, Washington, D.C.
1961	
Jan. 23–25	29th Annual Meeting, Hotel Astor, Times Square, New York.

IAS News

. . . a record of people and events of interest to Institute Members

15th Flight Propulsion Meeting Scheduled in March

Power for Aerospace Vehicles and Missiles Subject of Classified Conference

THE IAS 15TH Annual Flight Propulsion Meeting (Classified Secret) will be held in Cleveland, Ohio, March 10 and 11. Four technical sessions on Chemical Boosters, Nuclear Propulsion, Space Propulsion, and Status of Development Projects have been planned by the Committee, as well as a reception and banquet, and exhibits.

Program Chairman of the Committee, headed by members of the staff of Lewis Research Center of the National Aeronautics and Space Administration in Cleveland, is Carl F. Schueller, Chief, Propulsion Aerodynamics Division. Other principal planners are: Cochairman, David S. Gabriel, Chief, Propulsion Systems Division; Arrangements Chairman, Willson H. Hunter, Staff Assistant, Office of the Director; and Exhibits Chairman, Thomas B. Shillito, Head, Section D, Rocket Systems Branch, Propulsion Systems Division. In addition to those named, many others from the Cleveland-Akron Section of the IAS and the NASA staff are working on the plans for this meeting.

Lt. Gen. Bernard A. Schriever, USAF, Commander, Air Research and Development Command, will be guest of honor and principal speaker at the dinner to be held in the Rainbow Room of the Pick-Carter Hotel on Thursday, March 10.

Security clearance forms, which are required for this meeting, were available from the Meetings Department by return of the request form, mailed with the complete program to all IAS members early in January. Security arrangements are under the cognizance of the United States Air Force.

Fourteen papers are to be presented in the four sessions. Those definite at this writing are outlined below:

Chemical Boosters

"Status Report on Saturn," by Heinz H. Koelle, Chief, Future Projects Design Branch, Dev. Operations Div., ABMA.

"Present Status and Future Outlook for Large Solid-Propellant Rocket Motors," by Ernest R. Roberts, Manager, R&D, Aerojet-General Corp.

Paper on Air Breathing Boosters by Charles W. Frick, Jr., Chief Technical Engineer, Convair Div., General Dynamics Corp.

"Operational and Propulsion Requirements for Recoverable Boosters," by Darrell Romick, Manager, Astro Engineering, Goodyear Aircraft Corp.

Nuclear Propulsion

"Nuclear Pulse Propelled Vehicles," by Theodore B. Taylor, Technical Assoc. Director, Nuclear Pulse Propelled Vehicle Project, General Atomics Div., General Dynamics Corp.

"Characteristics of a Space Vehicle Using a First Generation Nuclear Engine," by Charles D. McKereghan, Res. Engineer, Denver Div., and Allan R. Siegel, Proj. Engineer, Nuclear Div., The Martin Co.

Carl F. Schueller, AFIAS
Program Chairman

Lt. Gen. Bernard A. Schriever, USAF, AFIAS
Dinner Speaker

"Nuclear Rocket Systems Design and Application," by S. V. Gunn, Chief of Nuclear Propulsion, R. F. A. Lem, and M. H. Rosenblum, Sr. Research Engineers, Rocketdyne Div., North American Aviation, Inc.

Space Propulsion

"Logistics and Application of Liquid Hydrogen in Space," by Richard C. Mulready, Project Engineer, XLR-115 Engine, and Charles H. King, Jr., Project Engineer, Advance Programs, Florida R&D Center, Pratt & Whitney Div., United Aircraft Corp.

"Propulsion Requirements for Rendezvous in Orbit," by Eugene Levin, Mathematician, Aeroastronautics, The RAND Corp.

"Propulsion Requirements for Soft Lunar Landing," by E. V. Stearns, R&D Scientist, Advanced Space Res., Missiles and Space Div., Lockheed.

"Power Plants for Atmospheric and Surface Vehicles on Mars," by William H. Krase, Engineer, The RAND Corp.

Status of Development Projects

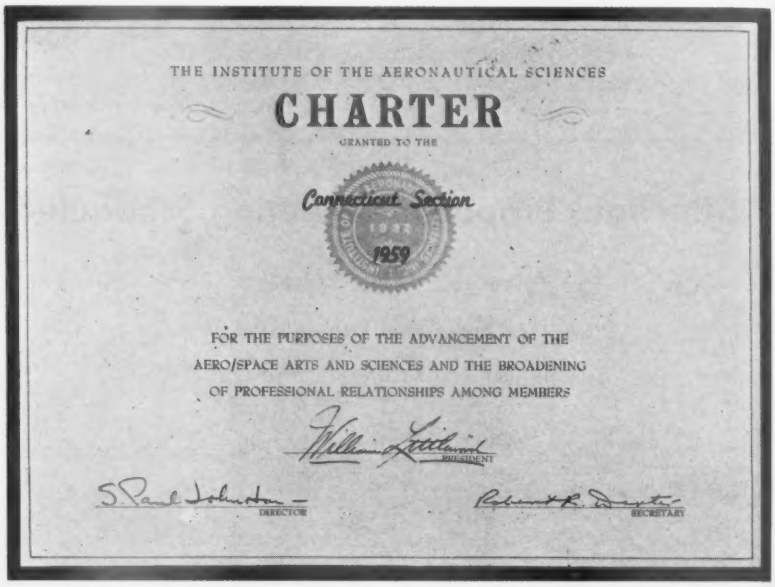
"Polaris Missile Development and Planning," by Comdr. C. A. Zimmerman, USN, Head, Propulsion Sect., Special Projects Office, Bureau of Ordnance.

"Minuteman Propulsion," by Col. Lang Ayres, USAF, Headquarters, Ballistic Missile Div., Air Research and Development Command.

Connecticut 35th Section

The Connecticut Section of the IAS was welcomed into the National organization at its inaugural meeting in West Hartford, Conn., on November 10. William Littlewood, IAS President for 1959, extended greetings, introducing Section Chairman Charles Chatfield, Secretary of United Aircraft Corp., and presenting him with the new section's charter. Other officers of the section were in turn introduced by Mr. Chatfield. They are, Vice-Chairman, Edward J. Odlum, Vice-President of Kaman Aircraft Corp.; Secretary, Lee J. Doyle, Engineering Manager, Maxim Silencer Co.; and Treasurer, Edward Sharp, General Manager, Jarvis Manufacturing Corp. Rossa Cole, Chairman of the New York Section, was present at the launching of the new Connecticut Section, which in the past had been served by the New York Section.

Creation of the new section came about as the result of a survey initiated by Carl W. Lemmerman of C. W. Lemmerman, Inc., and Wesley Kuhrt of United Aircraft Corp. Research Laboratories. IAS members resident and employed in Connecticut responded overwhelmingly in favor of forming the new section, the Institute's 35th. Membership is composed of over 300 engineers and scientists in the aerospace field.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The newly designed IAS charter (gold and blue color areas not shown here), presented to the Connecticut Section at its inaugural meeting on November 10. Similar certificates are being distributed to the other 34 IAS Sections.

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Corporate Member News

• **Aerojet-General Corp.** has combined its Architect-Engineer unit with Electronic Design groups into a new division. This division, to be known as AETRON, will be responsible for the development of facilities for the manufacture, testing, and development of weapons systems and space vehicles.

• **Douglas Aircraft Co., Inc.,** has organized two new corporate functions—Defense Programs and Commercial Programs. Within their respective areas, the two organizations will be charged with general direction and coordination of marketing activities, integrated planning, implementation and coordination of programs, and related activities.

• **General Precision Equipment Corp.** has announced the consolidation of its four principal subsidiaries—General Precision Laboratory, Inc., Kearfott Co., Inc., Librascope, Inc., and Link Aviation, Inc.—into a single company, General Precision, Inc. Effective early in January of this year, each of the merging companies became a division of the new firm, with managements remaining the same as before.

• **Janitrol Aircraft Div.** was recently purchased, along with its parent company, Surface Combustion Corp., by The Midland-Ross Corp., and will hereafter operate as Janitrol Aircraft, a division of Midland-Ross Corp.

• **Walter Kidde & Company, Inc.** . . . Aviation Div. has announced that its name was changed to Kidde Aero-Space Div., effective January 1, 1960.

• **North American Aviation, Inc.** . . . Autonetics Div. has announced the establishment of a European office in Geneva, Switzerland.

• **Ramo Wooldridge,** a division of Thompson Ramo Wooldridge Inc., announced that it has established an electronic field office at Sierra Vista in southern Arizona.

• **United Aircraft Corp.** has announced that its Research Department has been renamed United Aircraft Corp. Research Laboratories, marking a turning point in its activities from short-term and applied research toward basic research.

WG — **WHITTAKER GYRO:** Leading designer and manufacturer of electromechanical and non-electric gyroscopes, including rate gyros, vertical gyros, and position gyros. In addition, this Division is active in the sub-systems field with stable platforms, inertial guidance equipment, and auto pilots for missiles.

WC — **WHITTAKER CONTROLS:** Designs and produces aircraft and missile fluid control systems, subsystems and components. WC Products are in every production military aircraft and commercial airliner. In many of the nation's missile programs, Whittaker is also solving extreme fluid control problems.

MA — **MONROVIA AVIATION:** Producers of precision aircraft structural assemblies, Monrovia Aviation's products are installed on America's principal military and commercial jet aircraft. This Subsidiary also designs and manufactures customized portable air conditioning units for missile ground support purposes.

TS — **TELECOMPUTING SERVICES:** Skilled in the establishment and operation of data processing centers, primarily for military and civil agencies of the Government. At White Sands Missile Range, TSI processes and analyzes missile test data. At Vandenberg AFB, this Subsidiary provides data processing services for SAC's 1st Missile Division.

ES — **ELECTRONIC SYSTEMS:** Specialists in systems management, this Division also designs and manufactures a wide variety of equipment in the fields of electronics and nucleonics for highly classified Military Programs. In addition, Electronic Systems designs and produces Air Traffic Control equipment for the Federal Aviation Agency.

DI — **DATA INSTRUMENTS:** Leading designer and producer of data reduction systems for ground support and range instrumentations. Product line includes shaft rotation digital equipment, decommutators, and other highly complex and specialized instruments for missile and aircraft testing, telemetering and in-flight operation.

EC — **ELECTRONIC COMPONENTS:** Designs and produces components, including magnetic amplifiers, transformers, micro-miniature relays, delay lines and high temperature ceramic capacitors. These reliable components are being selected for installation in many of the country's principal missile and space programs.

CB — **COOK BATTERIES:** Designers and manufacturers of automatically and manually activated silver-zinc batteries for specialized missile application. These auxiliary power units provide primary or secondary electrical power. This subsidiary also produces power conversion and other electronic apparatus.

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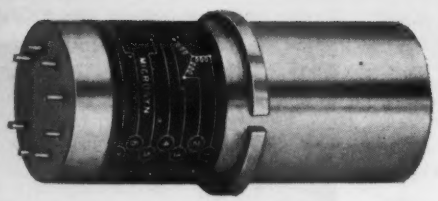

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Meet the Staff

An Aero/Space Engineering feature on personnel of the IAS

George Bunatta—"Record Holder"

George Bunatta, a statistician, is on the Institute's Membership Department staff where—since 1953—his duties have included processing of applications for graded memberships, preparation and checking of dues bill mailings, compilation of data pertinent to membership and individual subscriptions to AERO/SPACE ENGINEERING, and screening data for publication in the IAS Roster of Members. (The 1960 Roster will be published as part of *A/SE* in August.)

Mr. Bunatta joined the Institute's paid staff in March of 1943 as supervisor of the receiving, shipping, and mailing departments, and of three storerooms. These were located (indicating cramped IAS quarters of the time) on the 15th, 35th, and 51st floors of the R.C.A. Building in New York's Radio City complex of buildings.

Our "Meet the Staff" personality of the month is married to the former Anna M. Murphy. Their son, a married daughter, and four grandchildren are residents of California.—A.B.

IAS News

News of Members

James R. Anderson (A) has been appointed Eastern District Sales Engineer for Electronic Specialty Co. of Los Angeles. Mr. Anderson was formerly Senior Sales Representative with the Tapco Group of Thompson Ramo Wooldridge Inc.

Alexander H. Flax (M), Chief Scientist, USAF, relaxes with IAS President William Littlewood, prior to presentation of the Institute's 23rd Wright Brothers Lecture in Washington, D.C., on Dec. 17. Dr. Flax spoke before an audience of several hundred on "High Temperatures in Supersonic Flow."

James E. Bevins (A), formerly Director of Engineering, has been named Assistant General Manager of the Eclipse-Pioneer Div. of Bendix Aviation Corp.

W. R. Clay (M), formerly Assistant Manager, Engineering Dept., has been appointed a Division Vice-President and Engineering Department Manager by Radioplane, a division of Northrop Corp.

E. O. Cooper (M) has been named as National Director of Aircraft Services by the Bendix Aviation Corp. Mr. Cooper has been General Manager of the West Coast Sales and Service Div. since 1957.

Joseph W. Dalley (AF) has been named Professor and Head of the Department of Aeronautical Engineering at the University of Wichita. He will also serve as a consultant for Boeing Airplane Co. in Wichita. Dr. Dalley was formerly on the faculty of the Department of Aeronautical Engineering at the University of Texas.

Joseph L. Dickey (M) has been named Manager of the Air Arm Division's Bomarc Missile Seeker Project by Westinghouse Electric Corp. Prior to his new assignment, Mr. Dickey was engaged in antisubmarine warfare activities at Westinghouse.

Coleman duP. Donaldson (A), formerly sole proprietor of Aeronautical Research Associates of Princeton, announces the incorporation of the business. Dr. Donaldson has been elected President and a member of the Board of Directors of the new corporation.

Comdr. Robert F. Freitag, USN (AF), has been ordered to head the Navy's R&D program for satellites and space systems as Astronautics Officer in the newly formed Bureau of Naval Weapons. Commander Freitag was formerly Special Assistant to Rear Adm. Jack P. Monroe, Commander, Pacific Missile Range, Point Mugu, Calif., serving as Planning and Development Officer, and more recently as the Range Support Directorate Program Planning Officer. For services performed in connection with his assignment at Point Mugu, Commander Freitag was awarded the Navy's Legion of Merit.

William F. Gibbs (AF), President of Gibbs & Cox, Inc., in New York, was awarded the Michael I. Pupin Medal for outstanding "service to the nation" by the Columbia Engineering Alumni Association on December 9. Mr. Gibbs designed the liners "United States" and "America," as well as the Liberty ship of World War II. The award is the sixth and last to be made during the 100th anniversary year of the birth of Michael I. Pupin, engineer, teacher, and inventor.

Philip Harr (AF) has been appointed Director of Reliability Control for the Aircraft and Missiles Div. of the Fairchild Engine and Airplane Corp. Mr. Harr was formerly Director of Quality Control for the division.

Croydon H. Hartley (M) has been appointed Customer Liaison Manager for the Los Angeles Div. of Servomechanisms, Inc. Mr. Hartley transferred from his former position as President of the Company's subsidiary, Servomechanisms (Canada) Ltd.

Ephraim M. Howard (AF) is now assigned as Associate Project Engineer, Advanced Polaris Project. His former assignment was Head, Systems Integration Dept., Minuteman Engineering Div. In his new assignment, Mr. Howard will

William C. Holmes (AF) has been appointed Vice-President and Manager of the Space Communications Div., Radiation Inc. Prior to joining Radiation's West Coast division, Mr. Holmes was Assistant Weapon Systems Manager and Administration Director of the WS-117L Satellite Program at Lockheed Aircraft Corp.

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Large transparent plastic panels form the cockpit windows of the Vertol Aircraft Company's new YHC-1A helicopter. The plastic is firmly secured to the airframe by B. F. Goodrich RIVNUTS. About 300 are installed—quickly and easily—resulting in a finished seal that withstands both vibration and weather extremes.

One man fits the RIVNUTS into the hat section, working from one side. These RIVNUTS act as blind nutplates. Attachment screws tighten the molding strips, rubber and plastic in a firm, weatherproof grip.

This use of blind-fastening RIVNUTS insures a simple and very satisfactory method of window installation. In case after case, RIVNUTS speed assembly, cut labor costs, simplify design. If you'd like recommendations on a specific fastening problem, please send a print of your part.

"UNILOCK" thread-locking RIVNUTS

This special RIVNUT designed for aircraft and missile fastening has V-teeth under the RIVNUT heads to lock the RIVNUT to the material. Eliminates key and keyway; reinforces the hole.

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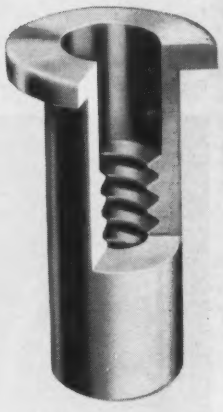

B.F.Goodrich ***Rivnuts***

share in responsibilities for the development of the Advanced Polaris Propulsion System.

Marvin J. Kahn (M) has been appointed Director of the newly organized Plans & Programs Div. of Aircraft Armaments, Inc. Mr. Kahn was formerly Assistant Director of Engineering.

Morris Lebovits (M) has been promoted to Chief of Astro-Aero Sciences at Solar Aircraft Co. Mr. Lebovits was formerly Section Chief of Aerodynamics for Solar.

Paul M. Leland (M) has been named to the Advanced Systems Planning Staff of Minneapolis-Honeywell Regulator Company's Military Products Group. Prior to his new position, he had been with Rosemount Aeronautical Labs of the University of Minnesota for over 11 years, most recently as Administrative Scientist.

Robert K. Lowry (M) has been transferred from his position as Western Regional Manager for Chicago Aerial Industries to Sales Manager for Pacific Optical Corp., a division of Chicago Aerial Industries.

James S. McDonnell, Jr. (F), President of the McDonnell Aircraft Co., has been elected Chairman of the Board of Governors of the Aerospace Industries Association, replacing C. J. McCarthy, Chairman of Chance Vought Aircraft, Inc.

A. I. Moskovits (M) has been appointed Head of Reliability Engineering Group, ASW Div. of Aerojet-General Corp. Mr. Moskovitz was formerly a Design Engineer with the company.

Paul Rosenberg (M), Director of Research of the consulting firm of Paul Rosenberg Associates, has been appointed by the National Academy of Sciences and the National Research Council to the Panel on Ship Operations of the Maritime Research Advisory Committee. The function of this panel is to advise the U.S. Maritime Administration on current and future R&D.

Edward Seckel (A), Associate Professor in the Department of Aeronautical Engineering at Princeton University, has been elected to the Board of Directors of Aeronautical Research Associates of Princeton, Inc.

Frederick J. Seufert (M) has been named Section Manager of the newly established Systems Development Section of Hoffman Laboratories Div., Hoffman Electronics Corp. Mr. Seufert previously was Operations Director for Hoffman's ULD-1 "Tall Tom" program.

Roger D. Sullivan (M), formerly Senior Mathematician, has been named Associate Consultant and Vice-President and member of the Board of Directors of Aeronautical Research Associates of Princeton, Inc.

Bernard H. Goethert (AF), *right*, Director of Engineering for ARO, Inc., was presented the Air Force Scroll of Appreciation at the Symposium on Simulated Altitude Testing of Rockets and Missile Components on Dec. 2 at Arnold Engineering Development Center. Lt. Gen. Bernard Schriever, Commander, ARDC, reads the scroll as L. J. Sverdrup, President of ARO, Inc., listens. Dr. Goethert received the scroll for work done at the AEDC in designing and developing the center's propulsion wind tunnel.

Armand J. Thieblot (AF) has been appointed Director of Engineering for the Aircraft and Missiles Div. of the Fairchild Engine and Airplane Corp. Mr. Thieblot had previously been with Fairchild from 1932 to 1951, when he left to form the Thieblot Aircraft Co., from which he has withdrawn to rejoin Fairchild.

George J. Vila (M) has been appointed Washington Manager—NASA for Convair Div. of General Dynamics Corporation, responsible for coordinating all Convair efforts relating to NASA projects. Formerly, Mr. Vila was Convair-Astronautics' representative for Air Force business.

Elmer P. Wheaton (AF), Vice-President —Engineering of Missiles and Space Systems for Douglas Aircraft Co., has been elected Chairman of the newly organized Guided Missile Council of the Aerospace Industries Association.

Necrology

Deryck C. Smith

The Institute has received news of the death on December 5, 1959, of Deryck C. Smith (AF), Executive of the NATO AGARD Structures and Materials Panel. Prior to joining NATO, Mr. Smith had been associated with the Royal Aeronautical Society as Technical Assistant to the Secretary.

Mr. Smith was born in Newmarket, England, in November, 1916. He took his higher education at Cambridge University, receiving his B.A. in 1938 and his M.A. in 1941.

Robert A. Schnelker (A)
August 2, 1959, Torrance, Calif.

H. C. B. Thomas (AF)
Farnborough, Hants., England

Wladimir A. Reichel (AF), Chief of Basic Design for the Norden Div., United Aircraft Corp., was presented the Department of Defense Medal for Distinguished Public Service, at a Pentagon ceremony on November 17, 1959. James H. Wakelin, Asst. Secretary of the Navy (R&D) *left*, presented the medal here examined by Vice Adm. John T. Hayward, Deputy Chief of Naval Operations.

Charles R. Strang (AF) has been named h head the newly established Advanced Researc Organization of Douglas Aircraft Co., Inc. M Strang was previously Chief Engineer of Dougla Tulsa Div.

He put a new twist in an old trick

His problem was to take a 3"x6"x 3-foot piece of wave guide tubing made of .08-inch thick aluminum and to twist one end 90° to the other *without buckling or stretching any part of it... so that a cross section taken anywhere along its length remained a perfect rectangle.*

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Columbus Section

IAS Aims & Objectives

"The Significance and Goals of the IAS" was the subject of a presentation by **S. Paul Johnston** (F), Director of the Institute, before the Columbus Section on November 19. Mr. Johnston's talk provoked interest and discussion regarding the present and future activities of the Institute.

JAMES P. LOOMIS, *Secretary*

Great Salt Lake Section

William Littlewood Lists Air Transport Kinks

The inaugural meeting of the 1959–1960 series of meetings was held at the Hill AFB Officer's Club on November 5, 1959. Guest speaker **William Littlewood** (HF), Vice-President, Equipment Research, American Airlines, Inc., discussed the natural problems associated with growth which have beset air transportation.

Mr. Littlewood stated that while there have been more passengers for the airlines to handle, there have also been more and faster airplanes to meet the public's demand. This has led to some rather prominent problem areas which involve the talents of several engineering fields. For example, there is the community problem related to airport location; the problem of transportation between air terminals and downtown locations of businesses; the problem of communications relative to securing reservations and providing movement instructions for the passengers; as well as the problem of communications relative to Air Traffic Control.

The handling of baggage is no small task when it is realized that a fast-moving transportation system requires prompt handling of individual luggage at each of the terminals, while maintaining mass transportation techniques. Considerable progress has been made in improving air travel techniques so that passengers may have safe and comfortable travel.

The increased demand for air transportation has brought about a desirable growth of the air transport unit. These larger units are able to provide added passenger comfort; however, complexities arise from the increased size, speed, and cruise altitudes. Navigation facilities are less efficient, and congestion in the vicinity of the air terminals has created certain safety hazards. These situations have gained the attention of the airlines, and due attention is being given to bring about a solution.

Mr. Littlewood illustrated the growth of air transportation by pointing out that the Ford Tri-motor, one of the earliest to carry passengers, cost approximately $55,000, whereas some of the more recent airlines cost in excess of 5 million dollars. The high cost of the modern transport is offset by the fact that it can carry a large payload at tremendous speeds, making the cost per ton-mile an economic feasibility.

If supersonic flight becomes a reality, Mr. Littlewood stated that we should expect a minimum speed of about 2,200 m.p.h., at altitudes above 60,000 ft. He noted that while such performance can be expected, a substantial effort will be required, and this will probably take more than a decade to accomplish.

KARL L. KOERNER, *Secretary*

Kansas City Section

Soviet Aeronautics

Dr. Grigori A. Tokaty, Visiting Professor of Aeronautical Engineering at the University of Kansas, now on leave as Head of the Aeronautical Department of the University of London's Northampton College, discussed **"Aeronautical Research and Education Facilities in the U.S.S.R."** at the November 23 dinner meeting.

Stating that the Soviet aeronautical industry is relatively young, Dr. Tokaty cited early efforts, a few wind tunnels, some aeronautical institutes, and the establishment of CAGI (the Soviet equivalent of our NACA). In 1936 a new CAGI came into existence, which by early examination of NACA efforts avoided mistakes and troubles. This organization is top secret, and stringent security measures are employed. Other important organizations are the Flight Research Institute of the Ministry of Aviation Production and the Scientific Test Institute of the Soviet Air Forces. All aircraft must have the stamp of approval of the latter group.

Dr. Tokaty described the Soviet system of education for the aeronautical engineer, explaining the concentration on aeronautics with the elimination of the liberal arts. He also explained the scientists' control by the state in fulfilling the requirements for a new design in accordance with schedules drawn up by the State Planning Commission in conjunction with the General Staff of the Armed Forces.

F. A. ROSENTHAL, *Secretary*

Los Angeles Section

Active Meeting Schedule; New Organization Effective

"Aerodynamic and Heat-Transfer Characteristics of Separated Flow Regions" was the subject of a paper presented by **Dr. A. F. Charwat** (M) at the November 24 Specialists' Meeting. Dr. Charwat, who is in charge of the High-Speed Aerodynamics and Propulsion Laboratory of the U.C.L.A., treated both subsonic and supersonic flow, describing the results of extensive tests using numerous experimental techniques to measure the properties of the separated region. These have included schlieren observation of the acoustic radiation, oil film visualization, and measurement of heat diffusion from a point source within the separated flow. A critical appraisal of these results indicates that simple analytical models of separated flow are adequate for describing the attendant pressure rise, but not adequate for computations of heat transfer within the separated region.

▶ **Dr. Abe Silverstein,** Director, Office of Space Flight Development, NASA, was guest speaker at the November 19 dinner meeting, with Elmer P. Wheaton, Vice-President, Engineering, Missile, and Space Systems, Douglas Aircraft Co., Inc., as guest chairman. In his presentation, **"Present Achievements and Future Promise of Space Flight,"** Dr. Silverstein summarized the status of the space program and planning for future projects. Drawing on recent discussions with scientists who are prominent in the Russian space program, he drew these comparisons between the U.S. and U.S.S.R. space efforts:

(1) The quality of instruments for scientific investigations in space is about equal in the two countries, with Russian equipment somewhat superior in some areas and somewhat inferior in others.

(2) Because they possess more powerful boosters than we have, the Russians can use boiler plate construction in their payloads, with consequent increase in reliability.

▶ On November 17, 34 members attended a field trip to the Los Angeles plant of the Firestone Tire and Rubber Co. In addition to a tour of the tire production facility, several movies of rubber development and uses were presented.

▶ **Robert B. Leighton,** Professor of Physics at C.I.T., discussed **"Solar Magnetic Phenomena"** at the November 10 Specialists' Meeting. Dr. Leighton, who recently developed a method for mapping the time variant magnetic field of the sun's surface, especially surrounding sunspots, flares, and other active regions, demonstrated the correspondence of these fields with observed fields of calcium light. A review of our knowledge of the cyclic nature of sunspots was also presented, along with movies of solar prominence.

As the 1960 program got into full swing, the L.A. Section was finding its new organizational structure to be increasingly effective. Two new posts have been added to the Executive Committee (Section Chairman, Vice-Chairman, Secretary, and Treasurer)—those of Operations Chairman, P. R. Compton, and Program Chairman, J. W. Wechsler. Committees which come under the Operations Chairman are Advanced Planning, Education, Information, L.A. Technical Societies Coordination, Membership, Public Relations, and Service. Directed by the Program Chairman are Committees on Dinner Meetings, Field Trips and Social Events, Historical, Security, Specialists Meetings, Summer Meeting, and Symposia.

The Section has found particular benefit in its 6-month standing clearance available to members. This process has permitted the Section to conduct a classified meeting with as little as 10 days' notice (8 weeks is standard). The convenience of the process has permitted the committees to schedule numerous classified meetings into their programs at a minimum cost and effort.

The recent formation of a Service Committee has also been effective in presenting an opportunity for members just entering industry to join actively in the IAS opera-

tion. Through their activities in providing assistance at the meetings, they gain experience which will make them valuable to the Section and the industry.

STARR J. COLBY, *Secretary*

New York Section

AHS President Looks at Soviet Aviation

Ralph P. Alex, Head of Component Design, Sikorsky Aircraft Div., United Aircraft Corp., and the 1959 President of the American Helicopter Society, addressed the New York Section of the IAS, November 19, on **"A Close Look at the Russian Aviation Industry."**

Mr. Alex had made a 17-day tour of the Soviet Union in his capacity as President of the International Helicopter Commission of the Federation Aeronautique Internationale. His talk was a running commentary on color slides which, in addition to providing a close look at Russian aviation, offered an interesting view of the Russian people and of life under the Soviet system.

While in Russia, Mr. Alex met and talked with Russian designers and officials of civil and military aviation. He was given the opportunity of inspecting various aircraft and of flying in several helicopters.

ROBERT L. GUSTAFSON
Advisory Board Member

Omaha Section

Officers Elected

Section Officers for the 1959–1960 year were elected on November 6: *Chairman*, S. M. Haley, Jr.; *Vice-Chairman*, R. S. Chubb; *Treasurer*, Major W. G. Hynds, USAF; and *Secretary*, M. J. McAlister.

M. J. MCALISTER, *Secretary*

St. Louis Section

Ion Propulsion System

"As in many other types of propulsion, there are a number of unsolved problems inherent in ion propulsion. The ultimate objective is a space vehicle system of optimum efficiency, but, at first, efficiency itself is not the paramount criterion from which all other design considerations must originate. It is of more immediate importance to design, construct, and ground test an operational vehicle and then optimize the system for the greatest overall efficiency." This was the conclusion drawn by **Andrew E. Lennert,** Project Staff Engineer, Propulsion Department, Nuclear Div. of The Martin Co., speaking before the October 21 joint meeting of the IAS, IRE, and AIEE.

Seated at the head table at the Nov. 19 dinner meeting of the New York Section are *(left to right)* Arthur Gilmore, George Fogas, Robert L. Gustafson, James Zusi, Rossa W. Cole, Ralph Alex, R. M. Woodham, Charles Tilgner, Nelson Shapter, and Theodore Hammen, Jr.

Mr. Lennert discussed the feasibility and regions of application of various propulsion systems and the direct conversion of nuclear energy to electrical energy. He predicted that a 20,000-lb. vehicle could be placed into orbit by 1965.

Comparisons based on specific impulse as a common denominator together with thrust to weight ratios and cost were presented for propulsive devices employing plasma, chemical, nuclear, solar sail, radio isotope, photon, and ion systems. Based on these presentations, the two systems most worthy of consideration were the ion and plasma. The anticipated efficiency of electrical conversions to propulsive force is approximately 92 per cent for the ion system compared to 50 per cent for the plasma system at specific impulses of 8,000 and 2,000 sec., respectively. The higher efficiency of the ion system potentially means a lighter power plant. Despite their excellent specific impulses, both of these systems have quite low thrust to weight ratios. Neither would be good for quick trips since the accelerations obtainable are in the fractions of a *g*.

Feasible systems for the direct conversion of nuclear to electrical energy were illustrated by slides. The electrical energy is converted to thrust by means of an ion generator and an ion accelerator. A feasible system employs cesium that is ionized by impingement on a tungsten grid. The internal space charge is reduced by producing electrons in close proximity to the positive ions in the accelerator. Mr. Lennert pointed out that the two biggest problems are (1) the neutralization of the space charge immediately aft of the vehicle and (2) a reliable power plant. Cesium has the desirable properties of a high atomic weight and a low ionization potential. The cathode temperature required is approximately 1,500° K.—a nominal temperature. On the other hand, the plasma system produces a temperature that is too high, thereby rendering it inefficient.

Mr. Lennert noted that the ion rocket achieves a number of economies—for one, the 20,000-lb. boost capability could be achieved. He had specifically pointed out why the ion system could be justified—mainly by the requirements of future space vehicles, requirements such as extreme reliability, development time cost, power source, specific power generation, specific impulse, payload capability, and many others. Even though the power plant required to generate the electric power is quite heavy, ion rockets offer overall weight-savings when compared with lower-specific-impulse propulsion systems for many space missions. The practical ion rocket requires (1) a high efficiency, (2) small weight, and (3) long operating life.

MARIANNE KELLY
Recording Secretary

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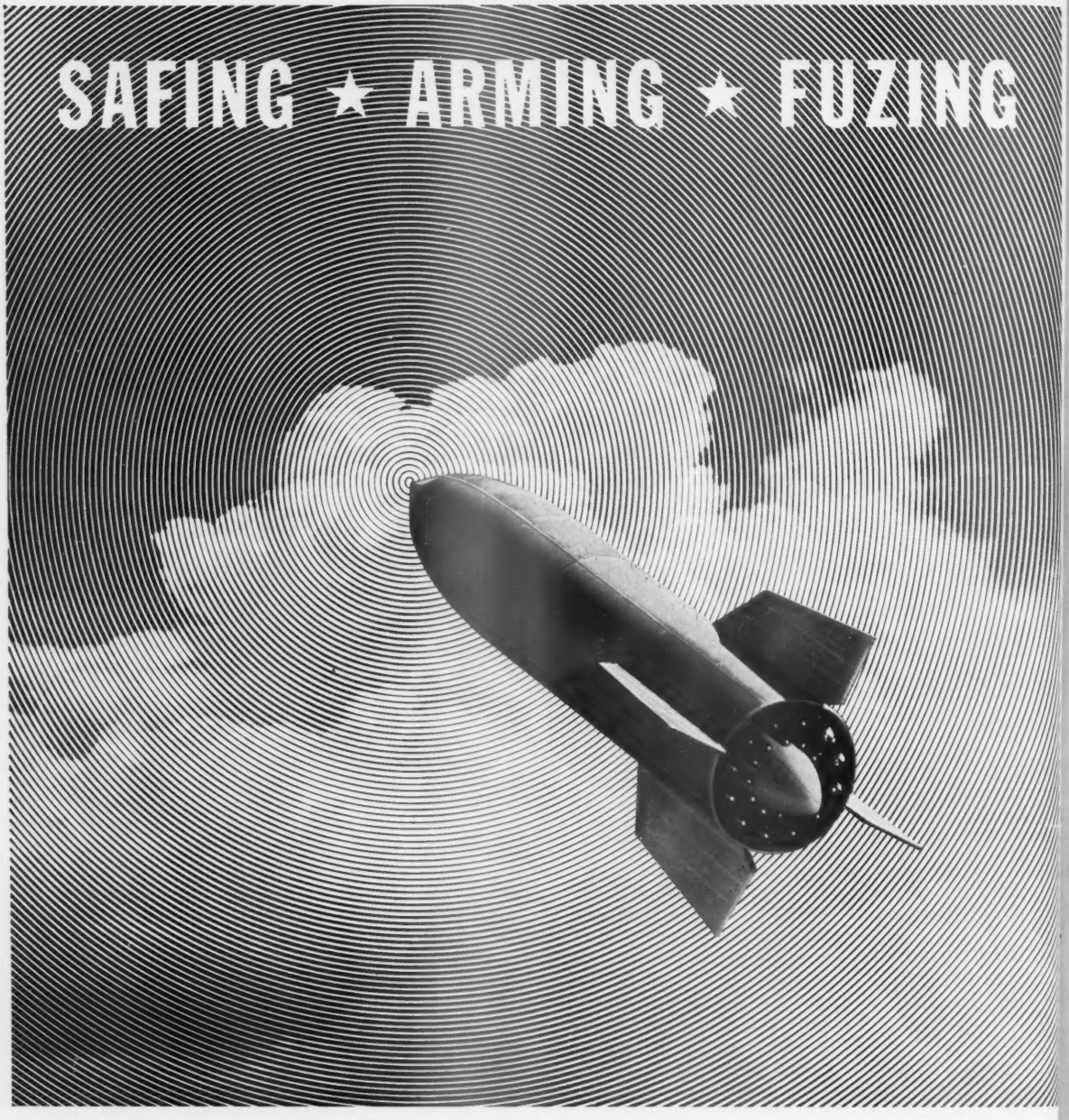

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DATELINE world

PROFESSIONAL NOTES AND REPORTS

Engineering and Scientific Briefs from Correspondents Around the Globe

Uses for Plasma Jet Discussed by U.S.S.R. Press

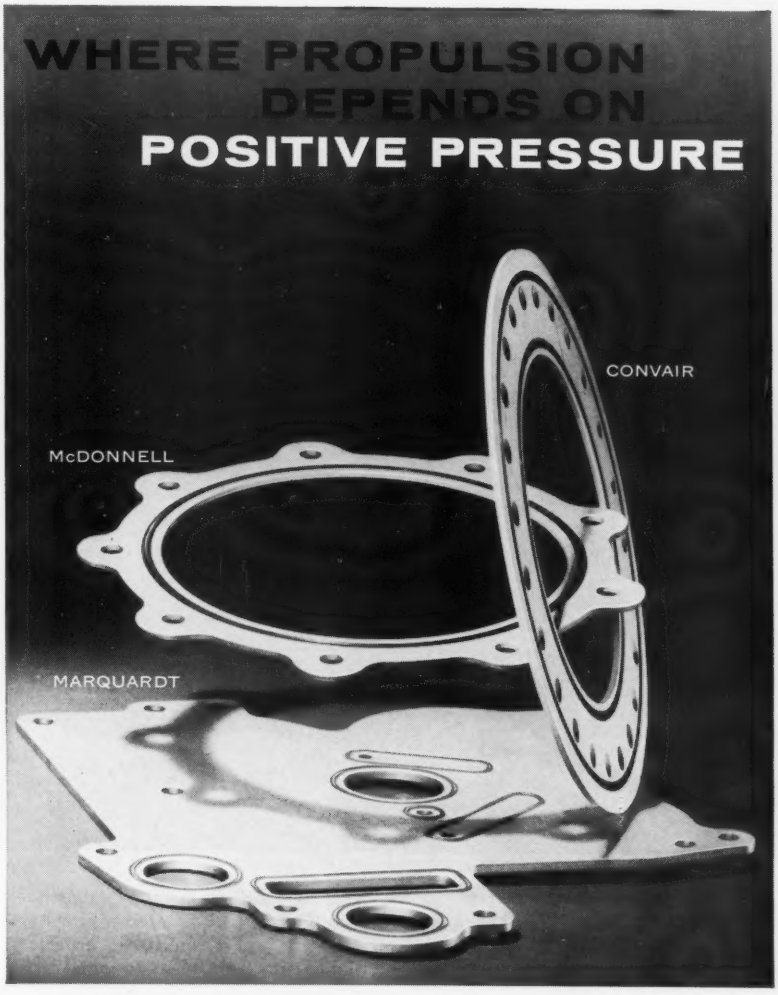
◆ Utilization of plasma jet for welding, brazing, surfacing, cutting, and scarfing is discussed in a U.S.S.R. press item noted recently. The item states that the Institute of Metallurgy of the U.S.S.R. Academy of Sciences has designed several types of plasma jet torches which have been successfully used in welding 0.2–1.0 mm. carbon and stainless steel sheets, without backing, and in cutting stainless steel, aluminum, and titanium.

Contributors of this item, I. D. Kutagin and A. V. Nikolayev, also furnished an article on plasma jet to an Academy of Sciences journal some weeks earlier. Here, they deal primarily with such basic characteristics as heat flow rate and coefficient of heat transfer from the plasma jet to the object being heated. They state that, as determined experimentally, the former value is considerably affected by the distance between electrodes, by gas consumption, and especially by current intensity, generally increasing with an increase in the value of these three factors. They say that the electrode material (tungsten or carbon) has no effect on the heat flow rate. The coefficient of heat transfer generally increases with increased gas consumption and decreases with an increase in current intensity, these Soviet investigators have found. They give the range of obtainable temperatures as from 8,000° to 10,000°C.

Gallium Derived From Slag Waste

◆ Hungarian scientists are using red slag waste from aluminum ore processing to obtain gallium and iron, according to report. One plant is said to be already producing 33 lbs. of gallium annually. The report states that the slag, containing up to 35 per cent iron oxide, is also smelted in blast furnaces for iron. Hence the famous Hungarian bauxites are now the source of iron, aluminum, and gallium.

Significance of this item is heightened by the important potentials seen for gallium in modern technology. Gallium has a melting point (86°F.) which is unusually low for a metal, expands upon solidifying, and supercools readily, remaining in the liquid phase at temperatures as low as 32°F. The useful liquid range of gallium is the widest of any element—more than 4,500°F. Among the uses of gallium already realized or being explored are (1) as a liquid seal in strongly heated apparatus; (2) enclosed in clear quartz, for a high-temperature thermometer; and (3) as a possible heat-exchange medium in nuclear reactors.



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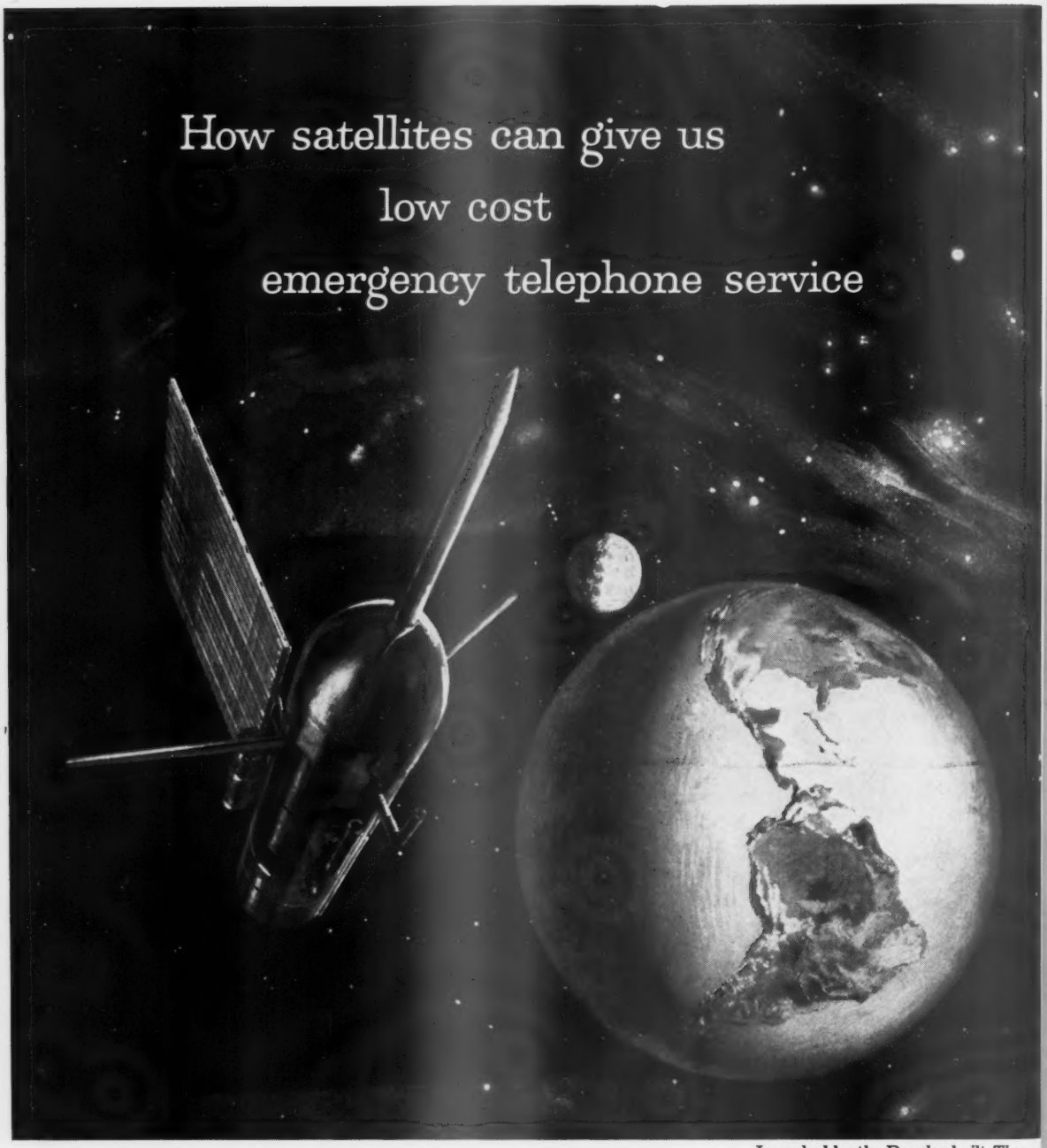
How satellites can give us low cost emergency telephone service



Launched by the Douglas-built *Thor* IRBM, satellites like this would relay telephone messages anywhere in the world without costly cables or towers.

Beyond their immediate military necessity, our present rocket and missile programs promise many vital peacetime benefits to us all...

Well past the drawing board stage are plans to use satellites as a low-cost emergency stand-by system to relay telephone calls around the world.

Your call would be beamed to a satellite, then bounced back to a receiving station on Earth. Cost is estimated at a fraction of what must be spent to install and maintain cables or radio relay towers.

While satellite telephone service is still in the future, *Thor*—the rocket that can put it into being—is thoroughly proved. Built by Douglas, maker of the DC-8 jetliners, *Thor* has been successful in more than 90% of its shots. It is key booster in the "Discoverer" firings and launched the first nose cone recovered at ICBM range.

Thor is another product of the imagination and experience gained by Douglas in 20 years of missile development.

DOUGLAS

MISSILE AND SPACE SYSTEMS
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EDITORIAL

A New VGM

One of the most productive of IAS activities in the past few years has been our Educational Program run generally under the supervision of the IAS Educational Committee and supported financially by income from the Minta Martin Aeronautical Student Fund (one-half million dollars donated by the late Glenn L. Martin). In addition to the normal work of our 80-odd Student Branches, the activity has included the operation of a half a dozen annual Regional Student Conferences from which selected papers of outstanding merit are submitted for national prizes, and the preparation and publication of special manuals (a) for the use of our Corporate Members in their engineering recruitment programs and (b) for the use of Vocational Guidance Counsellors and students in selecting courses of study.

The preparation of material for corporate use has been the official task of the IAS Engineering Career Development Committees. The original Committee was formed in 1955 in Los Angeles by several of our members who had recognized that our Corporate Member companies were themselves a prime source of information on engineering recruitment requirements and techniques. The Committee undertook to collect, compile, coordinate, and distribute such material in the form of a loose-leaf manual so that the composite experience of many organizations would be made available to all. The first results on the West Coast were so promising that the program was expanded to a national scale, and two other Committees were set up, one in the East and one in the Southwest. For the past two years these Committees have been working together—exchanging material and experiences and feeding the screened product into the ECDC *Manual*, copies of which are now in the hands of all IAS Corporate Members.

The other program—i.e., the supplying of vocational guidance material to teachers and students—has been equally successful. The first IAS Vocational Guidance Manual *A Guide to the Engineering Professions in the Aviation Industries*, intended primarily for faculty counsellors in high schools and junior colleges, was published in 1953. The project had been proposed by Wellwood Beall of Boeing during his term as IAS President in 1952. It described the nature and extent of the industry and the various kinds of jobs open to aeronautical engineering graduates. It also listed schools and universities where aeronautical engineering courses were offered. Some 30,000 copies were distributed through IAS Sections to schools all over the United States. A second edition (30,000) was published in 1954 and given equally widespread distribution. Another 30,000 copies of an extensively revised edition under a new title (*The Engineering Professions in Aviation*) were distributed in 1957.

This type of material proved highly useful for teachers and counsellors, but lacked direct appeal to the students themselves. There was a need, therefore, for a more personal approach—a somewhat "dressed-up" version telling the prospective engineering student what it meant to be an engineer, and how to go about preparing for an engineering career. To meet this requirement a new booklet *Your Career as an Engineer in Aviation* was prepared by our Member Services Department during the latter part of 1956. Many of our Corporate Members and many schools and individuals contributed to this effort. This proved so attractive to schools and students alike that three printings totaling 150,000 copies were distributed. This was as far as we could go. The demand for these booklets far exceeded our financial capability to supply them.

About a year ago it was decided that revisions were again in order to keep abreast of rapidly expanding aerospace techniques. It was agreed that a new booklet should be prepared, combining the best features of the preceding two. The job was assigned to Anthony Harris of our Staff, working under the direction of IAS Assistant Secretary Thomas Meskel. Those of you who attended the 28th Annual Meeting in New York have already seen the result of their labors. We are all particularly proud of the new Vocational Guidance Manual *Your Career as an Aero/Space Engineer*. We feel that it presents the case for studies in the aerospace sciences accurately and attractively with a minimum of "ballyhoo." Many have contributed material and ideas. The text has been read and reviewed by educators and many people in industry. The Staff worked long and hard to develop an attractive and readable format. Our thanks and appreciation go to all those who participated in the project.

With money presently available in the Minta Martin Fund we can print and distribute 100,000 copies. We would like to do more because we think that every high school student in the country who has any interest in science and/or engineering could read it with profit. In the hope that some means can be found to augment our own distribution, we are holding the plates for reprinting. If we could accumulate sufficient orders in bulk to total another 50,000 copies or over, the cost of printing would come to 15–20 cents per copy. Anyone interested in purchasing additional copies in bulk for his own distribution should communicate with Thomas Meskel, Assistant Secretary, IAS, at our New York Office.

S.P.J.

The story of the development of a parachute recovery kit with landing mats for shock absorbers—"the recoverable missile can be converted to tactical use simply by removing the recovery kit and installing the warhead, or vice versa."

TM-76 Mace Landing Mat Design

Kenneth Idomir
The Martin Company

A native of Rumania, Mr. Idomir was engineering task leader during development of the TM-76 Mace missile parachute recovery system. He has been a senior engineer associated with hydraulics design and testing on the Mace and P6M SeaMaster projects and is now engineering task leader on the preparation of hardened launch sites for the new inertially guided Mace B missile. During World War II, he served as gunner's mate on a Navy attack transport and was wounded in action in the Irish Sea south of Wales. Later he transferred to the Air Force and was an aviation cadet pilot trainee when the war ended. After the war, he obtained a Bachelor of Mathematics degree from Pennsylvania State University.

THE TM-76 MACE, manufactured by The Martin Company's Baltimore Division for the USAF, is a swept-wing, T-tail, jet-propelled, surface-to-surface, self-guided missile. Launched from a mobile zero-length launcher or from a hardened ground site, it is guided to the target by ATRAN, a radar map-matching system, or by an earth-referenced inertial guidance system. In test flights, it can be made recoverable by the addition of an interchangeable parachute recovery kit (Fig. 1).

Investigations, based on reports of Air Force guided missile test activities, revealed that the parachute system was twice as reliable as the skid-type system. The skid-type system also required a special landing area, flight control modifications for accurate approach and landing, and too much of the valuable space inside the missile. This system therefore was rejected. The contract subsequently awarded to Martin was for development of a parachute "recovery kit" with landing mats for shock absorbers.

This recovery kit, installed in place of the warhead in the warhead section, permits complete adaptability. The recoverable missile can be converted to tactical use simply by removing the recovery kit and installing the warhead, or vice versa.

Two landing mats (pneumatic shock absorbers), one installed forward and the other aft, reduce the descent velocity of the missile from parachute rate of descent to zero, without exceeding the design limitations of the missile. During final descent, the landing mat fairings are released by explosive bolts and the landing mats are exposed and automatically inflated to a predetermined pressure by air stowed in high-pressure pneumatic cylinders. Shear pin-type orifices are installed in the landing mats to control impact loading. The design criteria follow:

(1) Total missile weight (10,600 lbs.) is equally distributed between two landing mats ($W = 5{,}300$ lbs.).

(2) Parachute rate of descent V is 27 fps nominal at 4,500 ft. msl.

(3) Maximum missile load limit is 50,000 lbs.

(4) Landing mat efficiency is assumed to be 60 per cent.

Missile energy E_M is the kinetic energy of the parachute descent rate and the potential energy of position.

Thus, $E_M = (WV^2/2g) + WS$, where S is the stroke in feet, and $E_M = 60{,}000 + 5{,}300\ S$.

Landing mat efficiency is expressed as

$$e = \frac{\text{Missile Energy}}{\text{Landing Mat Energy}} = \frac{E_M}{E_B}$$

where e is efficiency.

The stroke required to dissipate the missile energy is therefore $S = E_B/50{,}000 = E_M/50{,}000e$, where $S = 2.43$ ft. or 29.2 in.

The landing mat configuration shown in Fig. 2 was selected for the following reasons:

(1) Structural limitations necessitated the addition of 11 in. to the landing mat height, which would not be utilized as a working stroke.

(2) To prevent the missile from rolling at ground contact.

(3) To avoid stress concentrations within the fibers of the landing mat itself.

The ideal landing mat would maintain a constant decelerating force by the use of a variable nozzle

However, since fabric design limitations of the landing mat at the time made this impossible, a fixed area orifice which would open at a predetermined pressure and stroke was chosen. Fig. 3 shows a plot of volume and area vs. stroke, and Fig. 4 shows a plot of flow rate vs. pressure.

With adiabatic conditions assumed, computations were then made to ensure that the missile would be stopped in the allowable stroke without exceeding design load limitations. Figs. 5 and 6 show that a variable weight can be recovered; however, considerable energy stored within the landing mat will be released, causing the missile to bounce. To prevent this bounce over the anticipated range of recovery weights, the landing mat (Fig. 2) was modified by adding another section and allowing the air to be throttled into it—i.e., the final landing mat configuration consists of a mat within a mat. (A compromise, experimentally determined, was made on throttling the outer mat, based on the final missile weight distribution. Residual energy varied from 600 to 2,000 ft./lbs. This means the missile will bounce from 1.5 to 5 in. on ground contact.)

In determining the effective recovery weight for each mat, consideration was given to:

(1) A missile landing attitude of 10° nose up or down. (The pitch rotation of the missile about the landing mat point of ground contact was not considered because this rotation will not appreciably affect the landing attitude.)

(2) The relieving effect of parachute lift during the landing process.

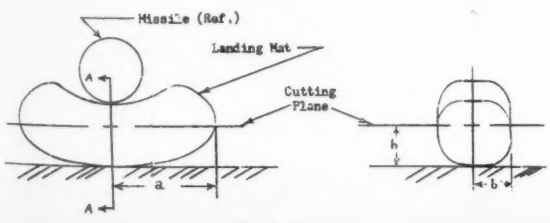
The following is an outline of the approach used in the design of the landing mats.

(I) Determination of Load vs. Stroke

In order to obtain the load vs. stroke curve (Fig. 3) of the landing mat, the variation of contact area, volume, and pressure with respect to stroke must first be determined.

Area vs. Stroke

An approximation of contact area is obtained when horizontal cutting planes are passed through the landing mat at various heights (see Sketch A). The height h of the cutting plane above the ground line represents one-half the total stroke since the landing mat deflects equally from the top and bottom. Section A-A shows the approximated contact area to be elliptical in shape. Utilizing a scaled layout, values for the semimajor axis



Sketch A.

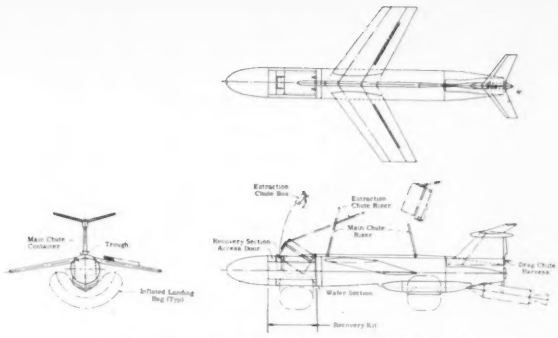


Fig. 1. Mace three-view, recovery kits installed.

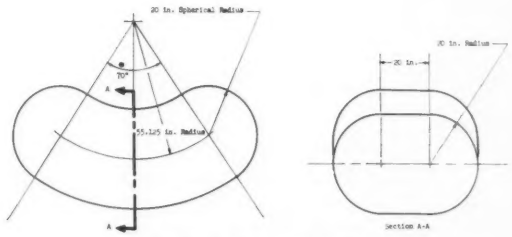


Fig. 2. Landing mat profile.

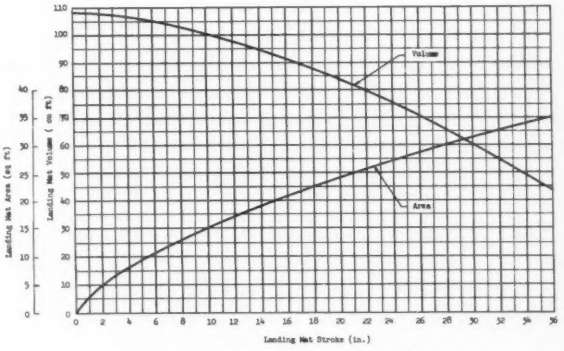


Fig. 3. Landing mat stroke relationship.

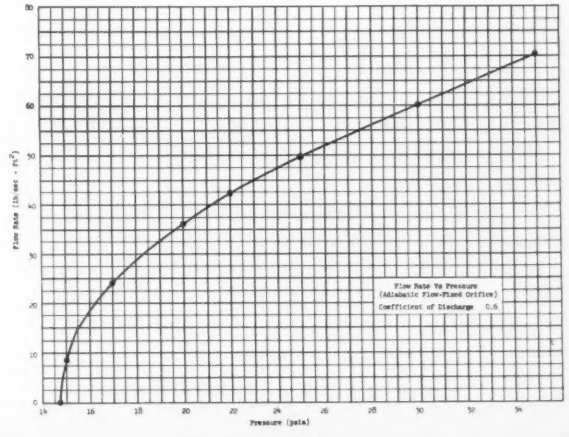


Fig. 4. Orifice flow rates.

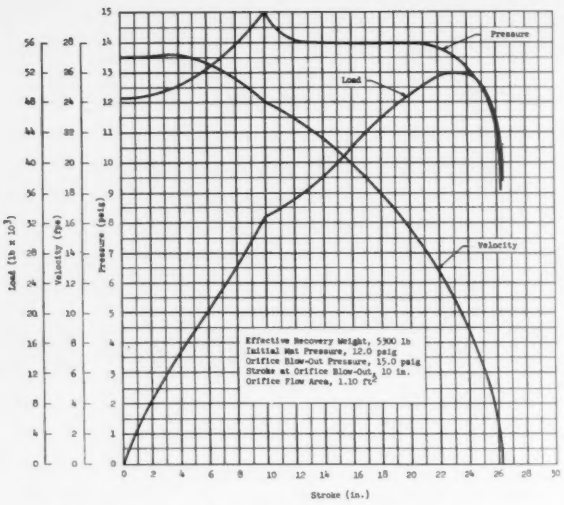


Fig. 5. Load, velocity, and pressure vs. stroke (5,300 lbs.).

a and for the semiminor axis b are obtained for various strokes:

Total stroke, $S = 2h$

Contact area, $A = \pi ab$

Volume vs. Stroke

The volume vs. stroke curve (Fig. 3) can then be determined from the plot of area vs. stroke after the total volume is known. The change in volume ΔV for a small stroke increment ΔS between the limits of points 1 and 2 of an increment is determined by the following equation:

$$(\Delta V)_{1-2} = 1/2(A_1 + A_2)(\Delta S)_{1-2}$$

where A_1 and A_2 are contact areas obtained from the area vs. stroke curve. Having determined the change in volume, the new volume is determined by

$$V_2 = V_1 - (\Delta V)_{1-2}$$

where V_1 is the volume at the beginning of the stroke increment, and V_2 is the volume at the end of the stroke increment.

Pressure vs. Stroke

It now becomes necessary to determine a pressure vs. stroke curve (Fig. 5). The following assumptions are made or reiterated at this point:

(1) An adiabatic compression from ground contact to orifice blowout.

(2) An adiabatic flow after orifice blowout so as to produce a constant internal landing mat pressure.

Utilizing the volume vs. stroke curve with the following equation, pressure vs. stroke is obtained for the adiabatic compression process between any two points (1 and 2) along the curve.

$$P_2 = P_1(V_1/V_2)^K$$

where K = adiabatic process constant, 1.4 for air.

Load vs. Stroke

The product PA at any point is equal to the load at that point.

Integration of the area under the load vs. stroke curve yields the total available landing mat energy.

(II) Computations for Pressure, Load, and Velocity vs. Stroke

Calculations Prior to Orifice Blowout

(1) Landing mat volume and area for any stroke are obtained from their respective curves in Fig. 3.

(2) Landing mat pressure P_0 is computed for any stroke S using the adiabatic compression relationship as follows:

$$(P_0)_2 = (P_0)_1(V_1/V_2)^K$$

where P_0 = landing mat pressure, psia; V = landing mat volume, ft.^{3}; and K = adiabatic process constant, 1.4 for air.

(3) Landing mat load F_T is computed for any stroke S by the formula

$$F_T = (P_0 - 14.7)\ (144)A$$

where F_T = landing mat load, lbs.; and A = landing mat contact area, ft.^{2}.

Calculations After Orifice Blowout

The following trial and error procedure was utilized in determining pressure, load, and velocity as functions of stroke. Orifice flow area, orifice blowout pressure, and stroke at blowout pressure were the trial parameters.

(1) The first step is the determination of assumed adiabatic flow rate per unit flow area. The general equation for adiabatic flow is

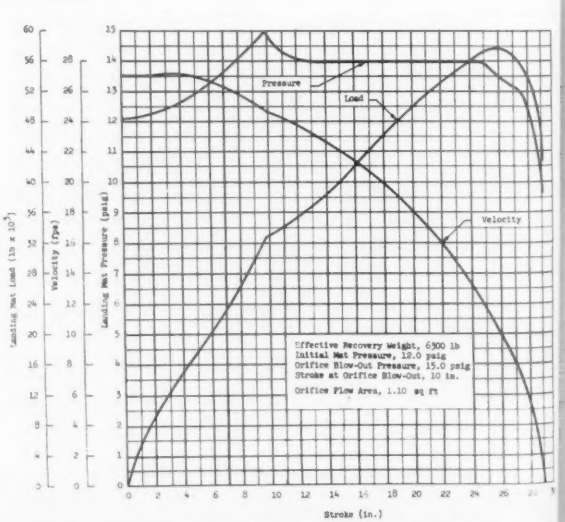


Fig. 6. Load, velocity, and pressure vs. stroke (6,300 lbs.).

$$w = CA(144\,P_1)\left(\frac{P_2}{P_1}\right)^{1/K} \times \sqrt{\left[\frac{\bar{M}}{T_1}\right]\left[\frac{2gK}{\bar{R}(K-1)}\right]\left[1-\frac{P_2}{P_1}\right]^{(K-1)/K}}$$

where

C = orifice coefficient, 0.6
A = orifice flow area, ft.²
P_1 = upstream pressure, psia
$\bar{M}$ = molecular weight of air, 28.97 lbs.
T_1 = air temperature upstream, 519°R.
g = gravitational constant, 32.2 ft./sec.²
K = adiabatic process exponent, 1.4
$\bar{R}$ = universal gas constant, 1,545
P_2 = downstream pressure, psia

By substituting known values and unit flow area (A = 1 ft.²), the equation becomes

$$w = 7.79\,P_1(P_2/P_1)^{1/K}\sqrt{1-(P_2/P_1)^{(K-1)/K}} \quad \text{lbs./sec.ft.}^2 \quad (1)$$

Eq. (1) is applicable only where the ratio of downstream pressure to upstream pressure is greater than 0.528 (or $P_2/P_1 > 0.528$) which is partial flow. When this ratio is less than 0.528 (or $P_2/P_1 < 0.528$), a full-flow condition exists and the ratio is constant at 0.528. Therefore, for full flow, Eq. (1) becomes

$$w = 2.019P_1 \text{ lbs./sec.ft.}^2 \quad (2)$$

Utilizing Eqs. (1) and (2) above for exhaust flow to atmospheric pressure, the flow rate per unit of flow area was plotted against upstream pressure (Fig. 4).

(2) An orifice blowout pressure and stroke are assumed compatible with the design criteria. The required initial landing mat pressure is determined by

$$P_1 = P_B(V_B/V_t)^K$$

where

P_1 = initial landing mat pressure, psia
P_B = orifice blowout pressure, psia
V_B = landing mat volume at orifice blowout, ft.³
V_t = total landing mat volume, ft.³

(3) Knowing the missile rate of descent at ground contact, the missile velocity at orifice blowout is now determined using the following equation (refer to Section III):

$$V_2 = \sqrt{\frac{2g}{w}\left[\frac{wv_1^2}{2g} + w(S_1 - S_2) - \frac{P_2V_2 - P_1V_1}{K-1} + P_a(V_1 - V_2)\right]}$$

(4) For this analysis, a realistic time increment Δt was chosen by assuming constant deceleration over the total stroke.

(5) With the data of points (1) through (4) established, the calculations after orifice blowout can be made. A step-by-step explanation follows in which the subscript b denotes that the value is taken at the beginning of the time increment, while the subscript e denotes that the value is taken at the end of the time increment.

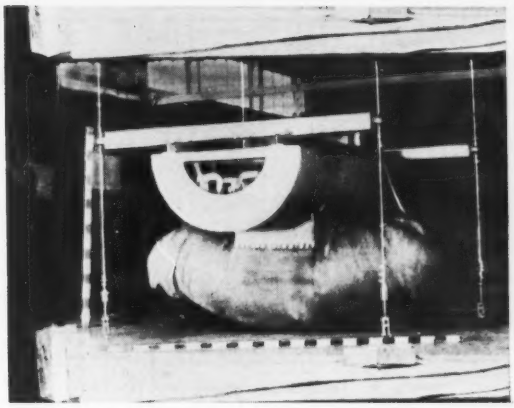
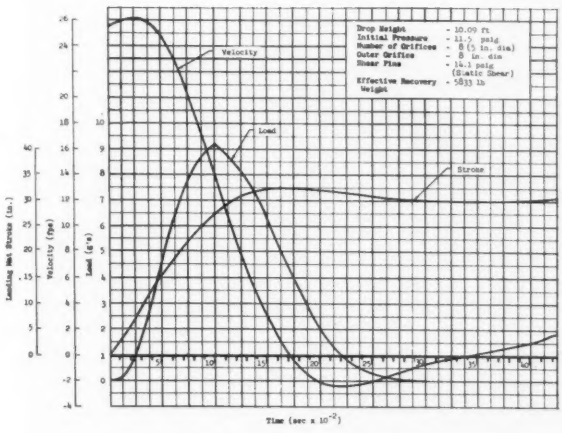


Fig. 7. Landing mat partially compressed.


Drop Height - 10.09 ft
Initial Pressure - 11.5 psig
Number of Orifices - 8 (5 in. dia)
Outer Orifice - 8 in. dia
Shear Pins - 14.1 psig (Static Shear)
Effective Recovery Weight - 5833 lb
Velocity
Load
Stroke
Landing Mat Stroke (in.)
Velocity (fps)
Load (g's)
Time (sec x 10⁻²)

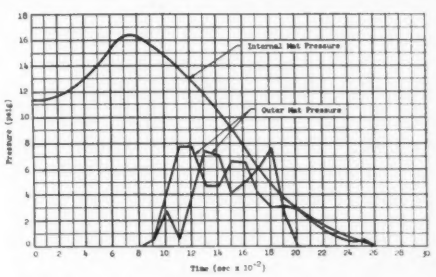


Fig. 8. Landing mat test data, Drop. No. 19.

Step 1—With the zero time reference chosen at the instant of orifice blowout, the known conditions at orifice blowout comprise the following starting data:

t = time, sec.
S = stroke, ft.
P_0 = mat pressure, psia
w = air weight = P_iV_i/RT lbs., based on conditions at ground contact, where P_i = initial landing mat pres-

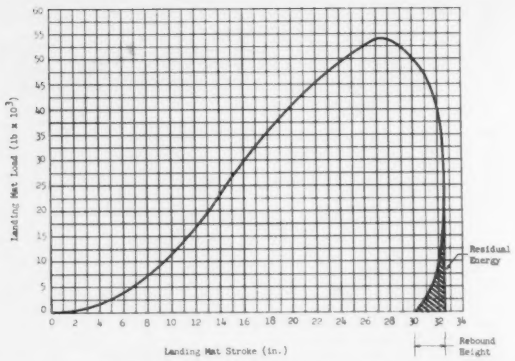


Fig. 9. Total load vs. stroke, Drop No. 19.

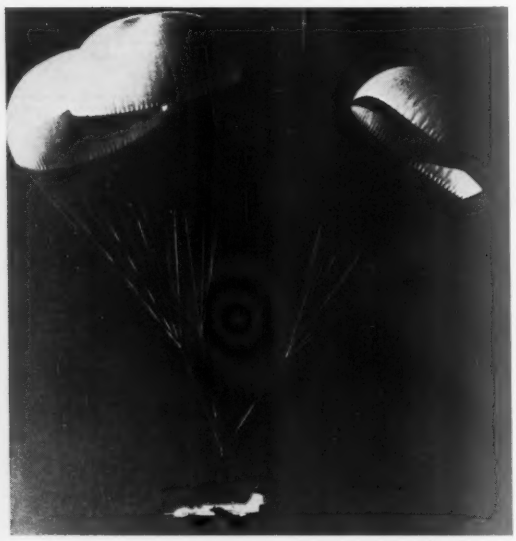


Fig. 10. Missile descending.

sure, psia; V_t = total landing mat volume, 108 ft.³; R = gas constant for air, 53.3; T = air temperature, 519°R.

V = landing mat volume, ft.³

A = landing mat area, ft.²

V_2 = missile velocity, ft./sec.

Step 2—The change in stroke ΔS is obtained by assuming that the missile velocity at the beginning of the time increment is constant for the entire time increment. Therefore

$$\Delta S = V_b(\Delta t)$$

$$S_e = S_b + \Delta S$$

Step 3—From Fig. 3, record V_e and A_e at S_e.

Step 4—Assume that the landing mat pressure $(P_0)_b$ is increased through an adiabatic compression process to a pressure $(P_1)_e$. The orifice flow rate is based on the arithmetic average of $(P_0)_b$ and $(P_1)_e$

$$(P_1)_e = (P_0)_b(V_b/V_e)^K$$

$$P_1 \text{ (average)} = [(P_0)_b + (P_1)_e]/2$$

Step 5—The flow rate per unit flow area w' is determined from Fig. 4 at the pressure P_1 (average) and is assumed constant for the duration of the time increment. It is now necessary to assume the orifice flow area A_0 to determine actual flow. The change in air weight Δw is found as follows:

$$\Delta w = (\Delta t)(A_0)(w')$$

$$w_e = w_b - \Delta w$$

Step 6—$(P_0)_e = w_eRT/144V_e$.

Step 7—Determine the average total force F_T which the landing mat will exert on the missile by

$$F_T = \left[\frac{(P_0)_b + (P_0)_e}{2} - 14.7\right](144)\left(\frac{A_b + A_e}{2}\right)$$

Note: F_T cannot exceed 50,000 lbs.

Step 8—The accelerating force of gravity was subtracted for each increment of time. Therefore, to determine the change in velocity, the following equation is used:

$$F_T - W = (W/g)(\Delta V/\Delta t) \qquad \therefore V_e = V_b - \Delta V$$

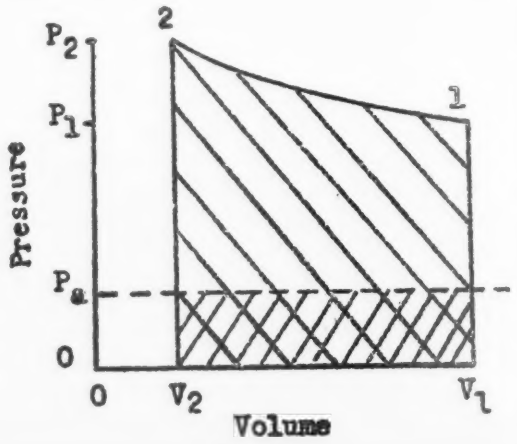
(6) The procedure outlined in points (2) through (5) is repeated until the missile velocity is zero at full stroke, with the total force never exceeding 50,000 lbs. Fig. 5 is a plot of a nominal landing load.

(III) Determination of Descent Velocity at Orifice Blowout

The total energy of the descending missile at the instant of ground contact, designated point 1, is a combination of kinetic and potential energies. This total energy at the instant of orifice blowout is represented by kinetic and potential energies plus the energy of work done by the descending missile in compressing the air in the landing mat Q. It follows that

$$(KE)_1 + (PE)_1 = (KE)_2 + (PE)_2 + Q$$

The energy required to compress the air is assumed to be that of adiabatic work. With reference to Sketch B, the total area under the curve as determined by integration consists of the energy available for compression (*upper portion*) plus the unavailable energy (*lower portion*) due to the effect of atmospheric pressure.



Sketch B.

The total energy under the curve is expressed as follows:

$$E = \int_{V_1}^{V_2} P\,dV = Cm^K \cdot \int_{V_1}^{V_2} V^{-K}\,dV$$

$$E = [(P_1V_1) - (P_2V_2)]/(K - 1)$$

Since the unavailable energy is represented in the sketch by a rectangular area, it is expressed as $U = P_a(V_1 - V_2)$.

Therefore, the work of compression becomes

$$Q = \{[(P_1V_1) - (P_2V_2)]/(K - 1)\} - P_a(V_1 - V_2)$$

Kinetic energy is determined by

$$KE = (1/2)(W/g)V^2$$

Potential energy is determined by

$$PE = WS$$

Substituting, the total energy equation becomes

$$\frac{1}{2}\frac{W}{g}\,V_1^2 + WS_1 = \frac{1}{2}\frac{W}{g}\,v_2^2 + WS_2\,\frac{P_1V_1 - P_2V_2}{K - 1} - P_a(V_1 - V_2)$$

Solving this equation for the descent velocity v_2 at orifice blowout,

$$V_2 = \sqrt{\frac{2g}{W}\left[\frac{1}{2}\frac{W}{g}\,V_1^2 + W(S_1 - S_2) - \frac{P_1V_1 - P_2V_2}{K - 1} + P_a(V_1 - V_2)\right]}$$

where

- v_1 = rate of descent of recovered missile, fps
- v_2 = descent speed at orifice blowout, fps
- W = effective landing mat recovery weight, lbs.
- S_1 = landing mat stroke at ground contact, ft.
- S_2 = landing mat stroke at orifice blowout, ft.
- P_1 = landing mat pressure at ground contact, psia
- P_2 = landing mat pressure at orifice blowout, psia
- V_1 = landing mat volume at ground contact, ft.^{3}
- V_2 = landing mat volume at orifice blowout, ft.^{3}
- P_a = atmospheric pressure, psia
- g = gravitational constant, ft./sec.^{2}
- K = adiabatic process constant, 1.4 for air

After the configuration of the landing mat was established mathematically, engineering information was released for the purchase of experimental mats for test purposes. Drop tests (Fig. 7) were then performed whereby rate of descent and various missile weights to be recovered were accurately simulated.

Fig. 11. Missile recovered.

All pertinent data were recorded on an oscillograph and analyzed.

Drop test No. 19 (Fig. 8) shows the worst missile recovery anticipated to be within the stroke limitations of the mat and within the maximum missile design load limit. Fig. 9 shows that the landing mat has an efficiency of 53 per cent for this worst condition.

A recovery flight-test program followed. Fig. 10 shows the missile descending with the landing mats fully inflated. Fig. 11 shows the undamaged missile successfully recovered.

The demonstrated reliability of the landing mats, parachute system, and automatic programing equipment unchanged for the last five consecutive preproduction flights concluded the development of the Mace Recovery Kit, now in production for the U.S. Air Force.

✦ ✦ ✦

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Under particularly severe aerodynamic heating, external missile surfaces tend to pyrolyze or to react directly with the atmosphere, and the reaction products are ejected into the boundary layer. Analysis of the surface reactions is essentially a problem in chemistry, the effect of the reaction products on the boundary layer (mass transfer effect), a problem in fluid dynamics. Whenever the chemical nature of the surface reaction can be established, these chemical considerations can be included in studies of the aerodynamic heating of missiles.

Aerodynamically Heated Surfaces—A Chemical Analysis

Howard Myers

Douglas Aircraft Company, Inc.

IN MANY DESIGN considerations it is no longer feasible to attempt to solve aerodynamic heating problems with the use of materials that are impervious to high heat fluxes. On the contrary, optimal design often results from exploiting the tendency of many materials to break down under severe heating. By selecting materials which decompose under severe heating and, in the process, absorb a large quantity of heat, it is possible to dissipate much of the aerodynamic heating along the external surfaces of the vehicle. This heat-absorbing process may be a change of state such as melting or sublimation, or a chemical reaction such as the depolymerization of a plastic. Furthermore, there is a second cooling effect available from a decomposing material, in addition to the direct absorption of heat. When the products of decomposition are ejected into the boundary layer, they tend to interfere with boundary-layer heat transfer. This effect is known as mass transfer cooling. At sufficiently high Mach Numbers, heat transfer from the boundary layer is reduced by 50 per cent or more. Materials which provide thermal protection through a combination of decomposition and mass transfer are now becoming known as ablating materials. Ablating materials have already demonstrated great effectiveness in re-entry body design and have many applications in the design of antimissile missiles, satellites, and space vehicles.

This paper presents a detailed analysis of the chemical behavior of ablative missile surfaces, including both decomposition reactions and mass transfer. In many important cases the two processes can be analyzed independently; this is particularly true when the process of surface decomposition is clean-cut and well understood chemically, as it is in the case of plastics such as Teflon.* In the remainder of the paper, the chemical

* Teflon is the E. I. du Pont de Nemours and Company registered trademark for tetrafluoroethylene plastic.

Symbols

Variables and Parameters

A	= kinetic frequency factor
C_H	= Stanton Number
E	= activation energy
G	= solar radiation heat flux rate
K	= kinetic specific rate constant
M	= mass
M_δ	= Mach Number at the edge of the boundary layer
Q	= heat of decomposition
Q^*	= effective heat of ablation
R	= molar gas constant
T	= temperature
ΔH	= molar heat of depolymerization
b	= lamina thickness
c_p	= specific heat at constant pressure
h_c	= heat-transfer coefficient
k	= thermal conductivity
$\dot{q}$	= heat flux rate
r	= recovery factor
t	= time
$\dot{x}$	= surface regression rate
α	= absorptivity
γ	= ratio of specific heats
ρ	= density
σ	= Stephan-Boltzmann constant
ρv	= mass flow rate

Subscripts

BL	= condition in the boundary layer
F	= net condition
T	= total condition
W	= condition at the outer wall
i	= condition of an interior lamina
o	= initial condition
s	= condition of the ablating material
δ	= condition at outer edge of boundary layer
1	= condition of the outermost lamina
2	= condition of the second lamina

Mr. Myers is a Research Specialist in Thermodynamics in Missile and Space Systems at Douglas. He received a Ph.B, a B.S. in mathematics, and an M.S. in chemistry from the University of Chicago and has studied further at the University of Southern California. He joined Douglas in 1956 after 3 years at the Hughes Research Laboratories. At Douglas, Mr. Myers conducts research in the fields of chemical kinetics and thermodynamics. He is responsible for the ablation design for the thermal protection of the Nike Zeus missile system. He is a member of the American Chemical Society, the American Association for the Advancement of Science, and the Electron Microscopy Society of America.

properties of Teflon are used to illustrate the scheme of analysis. However, the method of analysis is not restricted to Teflon, but is applicable to any surface material for which the reaction kinetics of decomposition have been established.

Chemistry of Teflon Decomposition

Teflon is a plastic material prepared by polymerizing tetrafluoroethylene, the monomer. The plastic consists of fluoroethylene chains, each about 10^5 molecular units long. When Teflon is heated in air above 700°F., the plastic does not char or burn, but decomposes with the evolution of gaseous tetrafluoroethylene. Decomposition is initiated when breaks occur in the long polymer chains. Once a chain breaks, it quickly unravels until only molecules of the monomer are left.

The chemical behavior of Teflon at elevated temperatures has been extensively studied[1–6] especially at E. I. du Pont de Nemours and Company and the National Bureau of Standards. From a chemical viewpoint the decomposition of Teflon is remarkably clean-cut, with only one reaction product—tetrafluoroethylene—being formed. The simplicity of the Teflon decomposition reaction permits an accurate determination of the rate of Teflon decomposition. Madorsky[2] has measured the Teflon decomposition rate by two different techniques. In one set of experiments, samples of Teflon were heated in an evacuated vessel at a constant temperature, and the rate of the mass loss of Teflon was determined by means of a spring balance incorporated into the apparatus. In other experiments, the decomposition rate was determined by following the pressure of the gaseous pyrolysis products. The two sets of experiments agreed closely and established that Teflon decomposition follows first-order reaction kinetics—that is,

$$-(dM/dt)_T = KM \qquad (1)$$

where M is the instantaneous Teflon mass, and K is a constant at any given temperature T. Madorsky also found that, as a function of temperature, the reaction constant for Teflon can be expressed as

$$K = Ae^{-E/RT} \qquad (2)$$

The terms A and E/R are constants; Madorsky's values are given in Table 1. More recently, Siegle and Muus[6] redetermined the Teflon decomposition rate and confirmed Madorsky's results. A comparison of the results is presented in Table 1 and Fig. 1. Comparing the experimental conditions of the two determinations, we find that the atmospheric pressure was varied over five orders of magnitude; but, at a given temperature, the Teflon decomposition rate was identical, except in a closed system at pressures approaching one atmosphere. Furthermore, the thickness of Teflon was increased from 0.001 to 0.51 in. without influencing the decomposition rate. This last fact indicates that the rate is truly first-order and not controlled by the rate of diffusion of the decomposition product from the interior of the sample.

The heat of depolymerization of Teflon, ΔH, at 298°K. is taken to be 41,050 cal./mole.[7] This value was obtained by a careful evaluation of best data on:

(1) The heat of combustion of polytetrafluoroethylene to CO_2 and CF_4, 118,800 cal./mole.[8]

(2) The heat of formation of CF_4, 217,600 cal./mole.[8–11]

(3) The heat of formation of C_2F_4, 151,800 cal./mole.[8]

(4) The heat of formation of CO_2, 94,052 cal./mole.[12]

The change in the heat of depolymerization with tem-

Table 1.

Investigator	E/R, °K.	A, Sec.$^{-1}$
Madorsky	40.5×10^3	4.7×10^{18}
Siegle and Muus	41.8×10^3	3.0×10^{19}

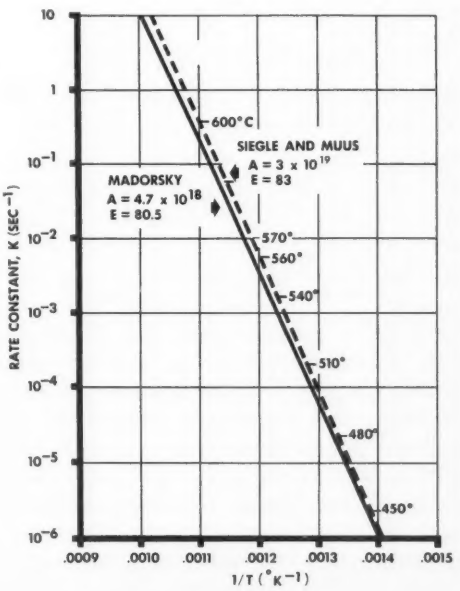

Fig. 1. Rate of Teflon decomposition.

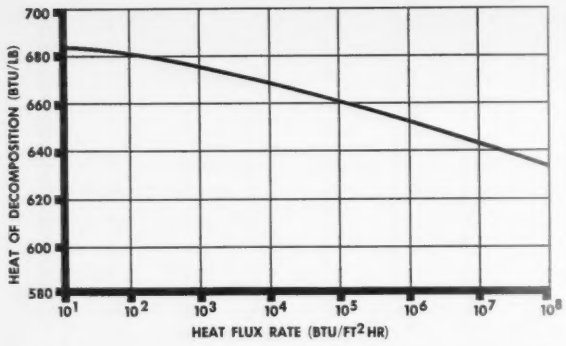

Fig. 2. Effect of heat flux rate on the heat of decomposition of Teflon.

perature can be determined from the differences in the heat capacity of the polymer and monomer and is

$$\Delta H = 41{,}050 - 3.5\,(T - 298) \qquad (3)$$

when the temperature is given in °K. The variation in the heat of depolymerization with heat flux rate is illustrated in Fig. 2. The relation between heat flux rate and temperature is discussed below.

Application to Missile Thermal Protection

Decomposing Surfaces

Heat-transfer analyses at the Douglas Missiles and Space Systems Engineering Department are performed by means of a general missile heating program coded for the IBM 704 electronic computer. In this program, heat transfer to a point on the missile skin is determined at a given point in the trajectory by (1) calculation of the local thermodynamic properties of the air at the outer edge of the boundary layer, (2) calculation of heat-transfer rate across the boundary layer, and (3) calculation of the temperature distribution within the missile skin. The thermal gradients within the skin, which may be a composite of several materials, are determined by dividing the skin into an appropriate number of laminas.

The effect of a decomposing Teflon surface on missile skin temperatures was assessed as follows: the net heat transfer to the skin is given by

$$q_T = h_C(T_{BL} - T_W) + \alpha G - \epsilon\sigma T_W^4 - h_C(T_W - T_1) \qquad (4)$$

where

$$T_{BL} = T_\delta\{1 + [(\gamma - 1)/2]rM_\delta^2\} \qquad (5)$$

When the Teflon surface reaches the temperature at which the rate of decomposition becomes significant compared to the rate of heat transfer to the surface, a considerable portion of the heat absorbed at the surface will go into decomposing the Teflon instead of further raising its surface temperature. To handle this situation, the computer program was revised to include an additional transfer term for the heat absorbed by decomposition. This term included the rate expression

$$-(dM/dt)_T = AMe^{-E/RT} \qquad (6)$$

and the program requires the determination of explicit values of T in order to obtain the necessary heat balance.

The results, when an analysis of a decomposing Teflon surface was made for the case of an antimissile missile trajectory, are presented in Fig. 3. The reduction in the maximum temperature of the steel, when coated with Teflon, is remarkable. Results such as these have stimulated the design of exterior missile structures out of aluminum or magnesium with a coating of a suitable plastic rather than exotic, high-temperature alloys, particularly in the case of transient applications.

A significant result of the calculations is the effect of the exponential character of the rate law on the value of the Teflon surface temperature: the surface temperature rises to about 1,100°F. and remains essentially constant—that is, the rate of Teflon decomposition is determined by the heat-transfer rate to the surface, and a steep increase in heat transfer can be accommodated by the commensurate increase in heat absorption with only a slight increase in surface temperature.

In routine design studies, it is convenient to replace the exact expression of Eq. (6) by a simplified approximation. The exponential rate law is replaced in the computer program by the requirement that the temperature of the outermost lamina does not increase above 1,100°F. During each computing time interval, the temperature T_1 of the outer lamina is computed from the energy balance:

$$(\rho c_p b)_1\,(dT_1/dt) = h_c\,(T_{BL} - T_W) + \alpha G - \epsilon\sigma T_W^4 - (k/b)\,(T_1 - T_2) \qquad (7)$$

Whenever T_1, as computed from Eq. (7), exceeds 1,100° F., T_1 is set equal to 1,100°F., and the amount of heat absorbed in decomposition by the lamina in each

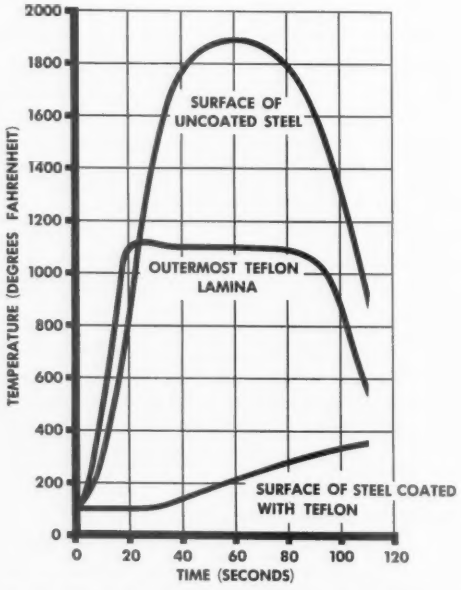

Fig. 3. Effect of a 0.2-in. Teflon coating on the surface temperature of 0.1-in. steel skin.

time interval is calculated from the term $\rho c_p b(T_1 - 1{,}100)$. When the sum of these terms for successive time intervals equals the heat per unit area required to decompose the lamina, the lamina is considered to have disintegrated. The assumption that there is a unique temperature of decomposition for Teflon does not introduce a significant error into calculations of thermal protection. Although the heat flux rate determines the surface temperature of the Teflon, the temperature has only a small effect on the heat of decomposition. Therefore, as can be seen in Fig. 2, a variance in the heat flux over seven orders of magnitude produces only a 7 per cent change in the heat of decomposition. Therefore, a heat of decomposition of 660 B.t.u./lb. corresponding to 1,100°F. may be considered a represen tative value for all heat flux rates. At higher heat fluxes, the decline in the heat of decomposition with temperature is greatly offset by the effect of mass transfer. The mass transfer effect is discussed in the next section.

Two assumptions implicit in applying the Teflon pyrolysis rate law to the missile situation require further comment: the question of the reversibility of the Teflon decomposition reaction and the possibility of the oxidation of the products of decomposition in the boundary layer.

In addition to pyrolyzing Teflon under a vacuum, Siegle and Muus degraded Teflon under various atmospheres, including pure tetrafluorethylene, Teflon pyrolysis products, air, and oxygen. In every case, a total pressure of 35 mm. was maintained. Under these conditions, the weight loss of the Teflon was less than in a vacuum, and the composition of the gaseous products differed significantly from that in vacuum pyrolysis. However, the overall rate of Teflon decomposition was still first order and independent of the particular atmosphere over the Teflon sample. In all experiments except those in vacuum, a white sublimate of low molecular weight was observed within the apparatus. The sublimate was found to be a white waxy mixture of fluorocarbons which melted around 480°F. and boiled above 575°F. without decomposition. The average chain length was 40–60 CF_2 units. The slower rate of pyrolysis in a closed system reflects a diminished rate of depropagation of the polymer chains due to the presence of the monomer. The sublimate apparently is formed by the recombination of fluorocarbon radicals prevented from depropagation by the presence of the monomer. The sublimate is formed initially in the polymer and causes a sharp reduction in melt viscosity. On the other hand, examination of Teflon surfaces that have been subjected to severe aerodynamic heating reveals no evidence for the formation of a Teflon-like sublimate. Therefore, in the analysis, the effect of atmosphere on the rate of decomposition has been disregarded, supported by the argument that the boundary layer continually sweeps the reaction products away from the Teflon surface, making the reverse, polymerization reaction improbable.

Similarly, the possibility of the oxidation of C_2F_4, say

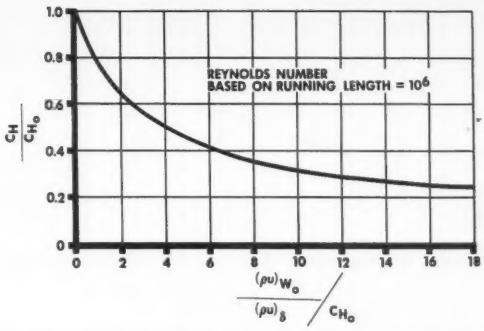

Fig. 4. Effect of C_2F_4 injection on skin friction for a turbulent boundary layer.

to CO_2 and CF_4, in the boundary layer has been disregarded. Unfortunately, the rate of oxidation of C_2F_4 has never been studied so a chemical kinetic analysis of the behavior of Teflon decomposition products in the boundary layer cannot be performed, and again an appeal to the experimental evidence must be made. C_2F_4 burns with a blue flame, and no such burning is observed in color films of Teflon models being decomposed by a supersonic blast of hot air at 4,000°F.

Mass Transfer

A scheme originally proposed as an alternative of ablation cooling is that of reducing the heat transfer from the boundary layer by blowing gaseous substances from missile surfaces into the boundary layer. Theoretical investigations by Rubesin[13] and van Driest[14] have indicated that a significant reduction in heat transfer can be obtained from moderate mass flow rates. Experimental work at the Langley Research Center of the NASA and at other research facilities has tended to confirm the promise of mass transfer cooling.

Since Teflon decomposes with the evolution of gaseous tetrafluoroethylene, the possibility of Teflon mass transfer was investigated. The analysis of the Teflon case is based on Rubesin's analysis with one important extension. In the original formulation, the coolant gas injection rate is considered as an arbitrary parameter, independent of the heat flux rate. In the case of the aerodynamic decomposition of Teflon, the mass flow rate of tetrafluoroethylene into the boundary layer is governed by the rate of heating of the Teflon surface. In addition, the equations were adjusted for an injectant molecular weight of 100, the molecular weight of tetrafluoroethylene.[15]

For the case of a Teflon surface, the mass transfer cooling effect is analyzed as follows: The degree of mass transfer cooling available from Teflon is directly proportional to the rate of energy absorption in Teflon decomposition; therefore, it is necessary to separate the incoming heat absorbed at the Teflon surface into the heat absorbed in decomposition, Q, and the heat absorbed in raising the temperature of the Teflon coating,

$$\int_{T_o}^{T} c_p dT$$

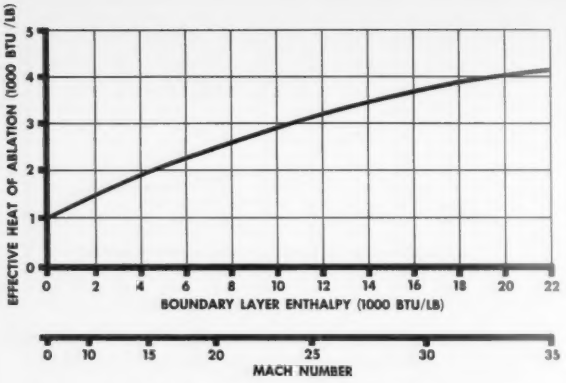

Fig. 5. Effective heat of ablation of Teflon.

At significant heat flux rates, the ratio of heat absorbed in decomposition to total heat input is

$$Q/(Q + \int_{T_o}^{T} c_p dT) \tag{8}$$

The rate of energy absorption is given by

$$\dot{q}_F = \dot{q}_T Q/(Q + \int_{T_o}^{T} c_p dT) \tag{9}$$

and the mass flow rate from the Teflon surface is

$$(\rho v)_W \dot{q}_F/Q \tag{10}$$

Therefore, $[(\rho v)_W/(\rho v)_\delta]/C_{H_o}$, the abscissa in Fig. 4, is given as

$$\frac{(\rho v)_W}{(\rho v)_\delta}/C_{Ho} = \dot{q}_T c_p/h_{C_o}\left(Q + \int_{T_o}^{T} c_p dT\right) \tag{11}$$

Therefore, evaluation of the right-hand side of Eq. (11) gives the corresponding value of $[(\rho v)_W/(\rho v)_\delta]/C_{Ho}$ and the reduction of heat transfer is obtained from Fig. 4. This analytical procedure has now been added as a subroutine to the IBM missile heating program.

The process of mass transfer makes a remarkable contribution to the overall thermal protection available from ablating substances. The significance of this contribution can best be demonstrated through the concept of the effective heat of ablation. The effective heat of ablation, Q^*, is defined as

$$Q^* = \left(Q + \int_{T_o}^{T} c_p dT\right)(C_{H_o}/C_H) \tag{12}$$

and represents a summation of the total heat required to decompose the material and an effective heat corresponding to the reduction in heat transfer due to the mass transfer process. For the case of Teflon, the effective heat of ablation is illustrated in Fig. 5, where 325 B.t.u./lb. are required to raise the temperature 1,100°F. and 660 B.t.u./lb. are absorbed in decomposition.

By a suitable use of the relations developed in the preceding paragraph, Eq. (12) can be rewritten in terms of experimental parameters:

$$Q^* = \dot{q}_{T_o}/(\rho v) = \dot{q}_{T_o}/\rho_s \dot{x}_s \tag{13}$$

The experimental determination of Q^* consists of first measuring the heat transfer $\dot{q}T_o$ to a nonablating calorimeter and then measuring the rate of surface regression $\dot{x}_s$ of an ablating material under the same conditions. Since Eqs. (12) and (13) are identical, it is therefore possible to compare analytical and experimental estimates of Q^* directly.

Conclusions

The analysis of ablating missile surfaces presented in this paper provides a basis for incorporating ablative cooling into missile design studies. For the case of Teflon, the overall theory has been confirmed by experiments with high-temperature air jets and free-flight test vehicles. The data from these test programs tend to verify the conclusions well within the uncertainties inherent in the various testing devices.

The design of missile systems to utilize ablative materials can be evolved with confidence only when it is possible to make realistic estimates of ablative protection required. Before the total weight of protective material can be calculated, the amount of thermal protection available from ablative materials must be determined over a wide range of heat flux rates. For any given material and trajectory, it is necessary to know the heat absorbed in raising the temperature of the material to temperatures where decomposition is rapid, the heat absorbed in decomposition, and the effective heat absorbed in mass transfer. Therefore, experimentally determined values of the effective heats of ablation, which represent the resultant of these processes of heat absorption, have little significance without independent estimates of the heat absorbed in the individual processes. Indeed, materials which seem to offer the greatest protection at the maximum heat flux rate of a trajectory do not always provide the most effective protection when the entire missile design is optimized.

At the present, the procedure in which one can have the most confidence is to make use in missile designs of those materials for which the detailed thermal behavior has already been firmly established, and at the same time to direct the experimental effort in materials research toward determining the heats and rates of reaction of promising ablative materials for future design.

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An application of flight flutter investigational experiences as a guide to the preliminary design and flight testing of relatively large external stores. The presentation is based upon results of the external stores flight flutter investigation of the U.S. Navy's Grumman F11F-1 fighter airplane. The program was performed with instrumentated test vehicles in a variety of aircraft and store configurations. The information here is intended to summarize the salient features of a wing/store flight flutter evaluation; scope and content of the discussion should be useful to the designer, dynamic analyst, and flight-test authority.

Flight Dynamics of Large External Stores

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Mr. Schaffer received his B.AeroE. and M.AeroE. degrees from New York University, College of Engineering. Since joining Grumman as a Structural Flight Test Engineer in 1955, he has been engaged in flutter, vibration, and structural investigations of high-performance aircraft. Other responsibilities have included dynamic stability problems and aerodynamic analysis of airplane and missile configurations. Mr. Schaffer is currently involved in the structural dynamics programs of the latest Grumman designs.

THE TACTICAL capability of high-speed military aircraft can be augmented, in many cases, by external stores. To the commercial carrier, cargo packs or external wing fuel tanks can be an asset in supersonic transport operations. However, to the dynamicist, external stores are potentially a mechanism for transforming the satisfactory damping characteristics of a clean wing into a dangerous, neutrally damped or unstable system.

Aircraft whose mission potential and/or performance would be enhanced by carrying large external stores have been in many instances restricted for various reasons:

(a) Minimum engineering efforts were spent in store and attachment design, as well as aircraft compatibility in the early design stages. When the store is finally considered, it is of necessity an appendage rather than an intrinsic component in the structural make-up of the airplane.

(b) The optimum store location and installation are often subordinated by other design considerations. These perplexing problems may result from the location of primary wing structural members, internal wing fuel cells, power plants, landing gear, or control systems. In military applications, the need for an attachment design that is versatile enough to accept a wide variety of stores further complicates the overall design of the store station.

(c) In the design of a large store the aerodynamicist's first concern may be to minimize drag. However, to retain a maximum air speed or Mach Number capability, proper design treatment includes a structural dynamic analysis in conjunction with the aerodynamic configuration study. A store having a high aerodynamic limit speed and a flutter speed within the airplane's flight envelope may exhibit aesthetic lines and even attain the design speeds in an empty condition, yet tactically or economically the store is of little value.

Prerequisites to Flight Flutter Testing

The state of flux common in the preliminary phases of an airplane design is conducive to unproductive initial flutter analysis. Similarly, the results of subsequent model tests, which are particularly dependent upon assumed stiffness and inertial parameters of the wing, pylon, attachments and store, are prone to inherent uncertainties. A ground vibration survey of the full-scale aircraft and store configuration is mandatory in order to verify the results of the foregoing analyses and tests and, possibly, to bring any discrepancies to the engineer's attention before first flight. A final theoretical flutter analysis made prior to flying the new store should account for any discordance in the preceding studies.

The proof of a stable store design can be shown only after an inclusive flight flutter test program has been

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The author wishes to acknowledge the excellent professional contributions of the Project Test Pilot, Ralph H. Donnell. The assistance and very helpful suggestions given by members of the Structural Flight Test Department are gratefully appreciated.

Fig. 1. Comparison of the original F11F-1 150-gal. external fuel tank (upper) with the alternate, lower inertia 150-gal. tank (lower). Note test instrumentation secured to the tanks.

completed. The flight-test group, including the project pilot, must be aware of any conditions predicted to be critical in the final flutter analysis. It is the joint responsibility of the dynamic analysts and the flight flutter test engineers to have at the disposal of the latter all the information concerning any predicted critical mode, including speeds, Mach Numbers, identifying characteristics, and nature—i.e., gradual deterioration in damping with air speed or abrupt crossover—of the impending instability.

Flight Flutter Testing—A Design Tool

In addition to verifying the predicted vibratory characteristics of the airplane-store combination, a flight flutter investigation should expose the innate dynamic properties that might not be obvious from inspection of analytical, model, and ground shake data. The complexity and length of flutter calculations combined with the usual priority system in the use of high-speed electronic computer facilities often make it impractical to solve for all the feasible conditions a design may experience in flight. Therefore, in the current state of the art, a flight flutter test program with external stores employing a properly instrumented aircraft is not only a proving ground for the dynamicist's predictions but also an infinite degree of freedom analog computer capable of delivering answers for all conditions ever expected in flight operations. Moreover, the full-scale flight flutter investigation is as essential a part of the design program

Table I. Store Physical Properties

Store Pairs	Weight, lbs.	I_y slug ft.^{2}	Length, ft.
Initial 150-gal. external tanks			
Empty	322	222.8	17
1/2 full	1,292	482.1	....
3/4 full	1,782	819.7	....
Full	2,262	1,053.2	....
Alternate 150-gal. external tanks			
Empty	268	113.6	15
1/2 full	1,238	255.1	....
3/4 full	1,728	495.2	....
Full	2,208	621.5	....
Sidewinders	310	84.0	9
Rocket packs	232	9.7	6.33
MK 83 bombs	1,970	228.0	10

as the preliminary analytics. The information gained from flight flutter testing a particular aircraft-store arrangement can be useful in future aircraft designs and store configurations. The recent F11F-1 external stores test program is a good example of the simultaneous two-pronged probe of flight safety and design research.

F11F-1 External Stores Flight Flutter Program

The F11F-1 airplane is a swept-wing supersonic, single-place, carrier-based fighter powered by a single J-65 turbojet engine equipped with an afterburner. Two versions have gone into service with the U.S. Navy. The major differences between the earlier version and the later one were a number of aerodynamic and manufacturing modifications designed to improve performance. However, both models are capable of equivalent air speeds in excess of 800 knots at low altitude and Mach Numbers greater than 1.5 at moderate altitudes. For the purposes of this paper, the most important differences between the earlier, or First Contract F11F-1's, and the later, Second Contract, model are several changes in wing construction, originating as weight-saving items. Approximately 36 lbs. were eliminated from the main wing panels by a change in the skin milling operations. An additional 34-lb. saving resulted from a redesign of the wing-tip assembly.

The combat potential of the F11F-1 airplane is to a large extent contingent upon the capabilities of its

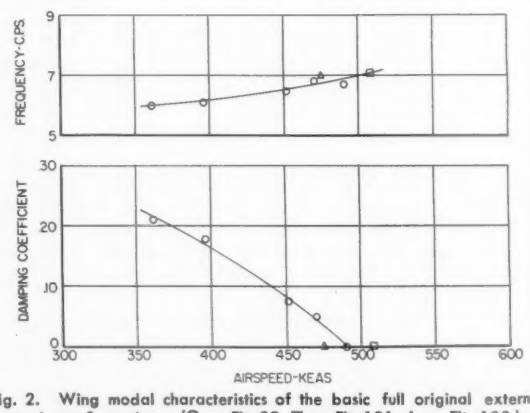

Fig. 2. Wing modal characteristics of the basic full original external-tanks configuration. (O = Flt. 99, □ = Flt. 101, △ = Flt. 102.)

four underwing store stations. Therefore, a foremost consideration in substantiating the tactical utility of the various external store combinations was determining the largest flutter-free flight envelope. The stores investigated included relatively lightweight air-to-air missiles, rocket packs, the heavier Mk 83 1,000-lb. bombs, and two types of 150-gal. drop tanks. (Table 1 summarizes the physical properties of some of the store configurations tested.) An incremental speed build-up program, utilizing pilot-induced lateral control motions for exciting the pertinent wing and weapons store modes, substantiated the antecedent analytical flutter calculations without incident. However, in the flight flutter investigation of the higher inertia, fueled drop tanks, a number of unusual experiences occurred noteworthy for both their dynamic analysis aspects as well as their flight-test connotations.

Initial Tests With 150-Gal. External Tanks

The original 150-gal. external tank is illustrated in Fig. 1a. This 17-ft., area-ruled store weighed 161 lbs. and when empty had a moment of inertia in pitch slightly less than that of a 1,000-lb. low drag bomb. The aerodynamic cleanliness of the tank's design was demonstrated by high Mach and high air-speed flutter checks limited only by safety considerations—i.e., avoidance of excessive dive angles and high load factors required during dive recoveries at low, near-ground altitudes.

During the first flight with full external tanks the damping following each test input decreased with increasing air speed (as indicated in Fig. 2) until at 490 knots, neutrally damped oscillations were excited. After two additional test flights it was established that the instability existed at high and low altitudes and was primarily a function of equivalent air speed or dynamic pressure. That is, the flutter condition was experienced within a narrow air-speed range of 475 to 500 knots estimated air speed (KEAS) with a Mach Number spread from 1.0 to 1.2.

Measures to improve the damping characteristics of the unstable wing torsion-tank pitch mode included a number of mechanical, inertial, and aerodynamic modifications. Attempts to increase the effective stiffness of the tank and pylon by preloading connections and couplings produced a moderate benefit and resulted in a V_f of 540 knots. Moving the fueled tank's center of gravity 10 in. forward, by replacing 25 gal. of fuel with styrofoam in the aft ends of the tanks, was ineffective (V_f of 480 knots). The addition of 5-sq.ft. horizontal fins to the tail ends of the tanks increased the flutter speed from 475 to 523 knots, besides fulfilling their primary function of stabilizing the tank during ejection.

The flutter limitations uncovered during tests of a First Contract F11F-1 airplane made it mandatory to verify the condition on a Second Contract vehicle—i.e., an F11F-1 employing the lightened wing construction. The initial tests with the lightened main wing

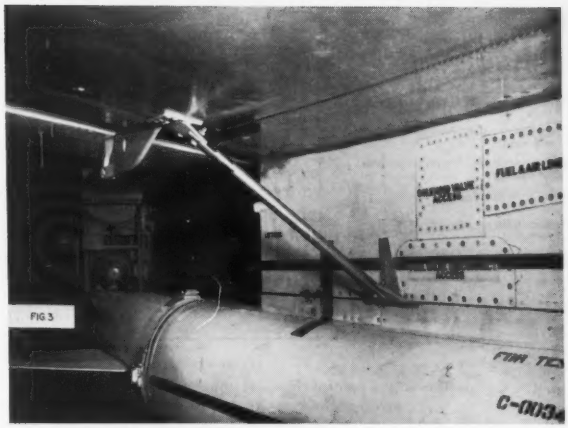

Fig. 3. Steel pylon-to-wing support strut.

panels and full drop tanks indicated a 462-knot neutral damping speed, as well as several other peculiarities, to be discussed shortly. Subsequently, internally ballasted wing tips were tested with limited results. The weight and inertial statistics of the different combinations of wings and tips flight tested are given in Table 2. The 96-lb. wing-tip configuration resulted in a 506-knot flutter speed. A steel pylon support produced essentially the same improvement as the heavy wing tips. An experimental set of tanks employing heavier gage sheet metal construction (increasing the weight of each tank 12 lbs.) was evaluated; however, no appreciable change in either vibratory characteristics or neutral damping speed was discernible. The bar chart in Fig. 4 summarizes the respective flutter speeds of each modification made to the original area-ruled drop tank.

Each of the foregoing innovations offered some degree of improvement; therefore, a composite modification consisting of finned, thick-skin shimmed external tanks, employing diagonal steel pylon support struts in conjunction with 96-lb. steel pylon support struts in conjunction with 96-lb. ballasted wing tips was evaluated on the Second Contract test vehicle. Although this configuration yielded the highest neutral damping speeds recorded with the full original drop tanks, the inherent weight penalties of this fix were thought to be a rather severe tactical handicap for the overall airplane mission. In addition, tests with

Table 2. Wing Weight and Pitching Moment of Inertia

Design Configuration	Empty Wing Weight, lbs.	Fuel Cells I_y slug ft.^{2}	Full Wing Weight, lbs.	Fuel Cells I_y slug ft.^{2}
1st Contract main panels, 59-lb. tips	1,966	556.1	3,208	739.1
2nd Contract main panels, 42-lb. tips	1,896	529.8	3,138	712.8
2nd Contract main panels, 59-lb. tips	1,930	553.0	3,172	736.0
2nd Contract main panels, 96-lb. tips	2,004	588.6	3,246	772.4

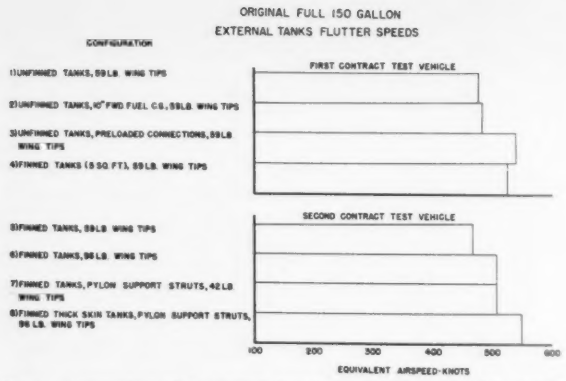
ORIGINAL FULL 150 GALLON
EXTERNAL TANKS FLUTTER SPEEDS
CONFIGURATION
FIRST CONTRACT TEST VEHICLE
1) UNFINNED TANKS, 89 LB. WING TIPS
2) UNFINNED TANKS, 10" FWD FUEL C.G., 89 LB. WING TIPS
3) UNFINNED TANKS, PRELOADED CONNECTIONS, 89 LB. WING TIPS
4) FINNED TANKS (5 SQ. FT.), 89 LB. WING TIPS
SECOND CONTRACT TEST VEHICLE
5) FINNED TANKS, 89 LB. WING TIPS
6) FINNED TANKS, 98 LB. WING TIPS
7) FINNED TANKS, PYLON SUPPORT STRUTS, 42 LB. WING TIPS
8) FINNED THICK SKIN TANKS, PYLON SUPPORT STRUTS, 98 LB. WING TIPS
100
200
300
400
500
600
EQUIVALENT AIRSPEED-KNOTS

Fig. 4. Comparison of the neutral damping speeds of various full original external-tanks configurations.

partially full drop tanks intimated that a more efficient solution to the problem was on the horizon.

Partial Fuel Tests With Original External Tanks

The classical flutter evidenced by the original area-ruled external tank when full was supplemented by damping problems under more unusual circumstances.

An investigation of the original external tank's dynamic properties with partial fuel quantities was conducted in conjunction with the full tank tests. The partially full configurations were flown in hope of finding a satisfactory fuel volume that would permit flight up to and including maximum attainable speed. In both the 1/2- and 3/4-full tank conditions, favorable damping resulted in level flight and dive attitude test maneuvers to limit speed, approaching 800 KEAS. However, in high speed, climb attitude recoveries from afterburner dives at equivalent air speeds greater than 600 knots, very low, unacceptable damping was exhibited by the provoking wing torsion-tank pitch mode. Whether induced intentionally or by an inadvertent gust, the oscillation persisted 50–60 knots below the onset speed.

This condition was encountered only while rounding out of high-speed dives with partially full drop tanks. Although the recoveries in several cases imposed as much as 4*g* on the aircraft, immediately before the test maneuver the airplane was at a load factor slightly in excess of one in the normal plane and decelerating at 3/10 of a *g* longitudinally. A review of all pertinent information indicated that the airplane was (1) nowhere near a stall condition and (2) the mass of fuel was generally concentrated along the bottom and forward part of the tank before and at the time the oscillations were induced.

Effect of Engine Throttling

Throughout the early phases of the external tank flight flutter investigation, damping of sustained oscillations could be accomplished by reducing power and air speed. During the latter tests with the Second Contract vehicle it was discovered that abrupt engine throttle excited an undamped wing torsion-tank pitch mode, whereas without throttling, acceptable damping characteristics were recorded at similar and higher speeds. These throttling peculiarities were observed at high and low altitudes from a supersonic Mach Number of 1.1 to a low subsonic Mach Number of 0.6, and as low as 365 KEAS. The characteristics were exhibited in both the full and 3/4-full external tank configurations, with and without fuel in the internal wing tanks. The situation was particularly poor since the last means of reducing air speed quickly was now, potentially, as dangerous as suddenly deflecting the dive brakes or applying load factor rapidly.

Study of the phenomenon revealed that the oscillations, induced by abruptly throttling the engine to idle, resulted from inlet spillage. Estimates of the mass flow immediately before and after throttling indicated that a large portion of the entering airflow was rejected by the duct inlets during a short time interval. An interesting verification of the condition was made by the project test pilot. During a flight when the prevailing atmospheric conditions were conducive to flow visualization about the airplane, the pilot *saw* the flow emanating from the lip of the duct and impinging as far outboard as the wing fences and probably to the external tanks under the wing. Although this condition may be looked upon as a forced response, it is, nevertheless, purely academic whether a wing is lost as a result of classically induced flutter or a duct spillage forced excitation. The consequences to the air crew are the same.

Shorter and lower inertia stores including MK 83, 1,000-lb., low-drag bombs evidenced satisfactory damping after abrupt engine throttle maneuvers. For the instability to manifest itself, apparently a long, relatively high inertia store must be mounted on the inboard pylon.

Additional Flight Testing

The flight flutter investigation of the F11F-1 test vehicles uncovered several other developments.

Investigation of a simulated fuel sequencing double failure on the Second Contract test airplane—namely, malfunctions resulting in full external tanks and empty internal wing fuel cells—indicated that neutrally damped wing-tank oscillations could be induced at lower air speeds than in the normal fuel sequencing condition (i.e., full wing cells with any quantity of fuel remaining in the external tanks).

In light of the external tank problems experienced on the Second Contract vehicle, the four Sidewinder

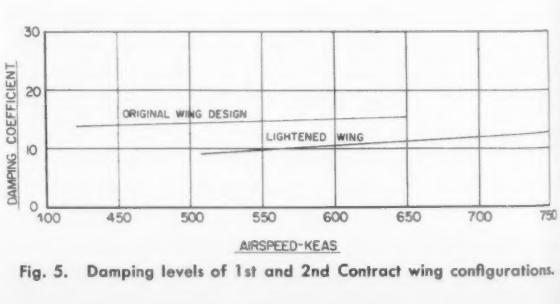

Fig. 5. Damping levels of 1st and 2nd Contract wing configurations.

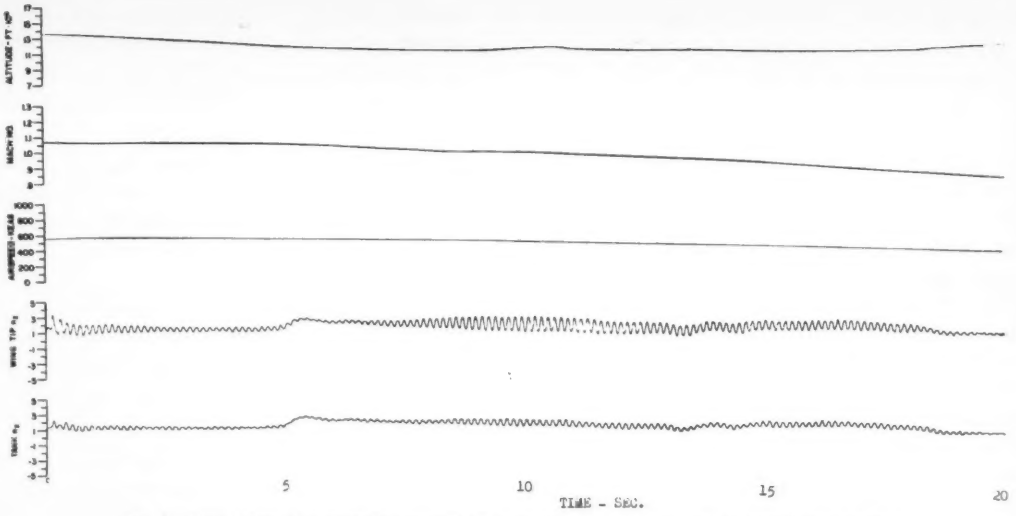

Fig. 6. Time history of a neutrally damped test maneuver, and the results of 2g load factor pullout.

missile configuration, previously flight tested on the First Contract flutter testbed, was reinvestigated on the lightened wing F11F-1. A comparison of results is presented in Fig. 5. The level of damping although still satisfactory is generally 1/3 less than that exhibited by the *heavy wing* F11F-1. The satisfactory results of throttle-cut maneuvers in this configuration also lent credence to the conclusion that long high inertia stores at the inboard stations are required for a throttling-induced oscillatory problem to exist.

The subject program revealed that the addition of comparatively low inertia air-to-air missiles (Sidewinder) to the outboard pylons produced a beneficial effect on both the full tank and the partially full tank dive recovery vibratory problems of the original area-ruled external tanks. With full external tanks and two Sidewinder missiles the flutter speed was approximately 20 knots higher than the onset of neutral damping without the Sidewinders. In the partially full tank condition, satisfactory damping was evident up to and including maximum effort dives and recoveries, the latter at speeds in excess of 640 KEAS. Nevertheless, these virtues are of little tactical use—once the missiles are expended the pilot may find himself in a potentially unstable flight regime.

A Satisfactory External Tank Configuration

The postulation that 300 gal. of jet fuel could be carried externally without resorting to a speed restriction on the aircraft demanded a more fundamental approach. Complicating the task were several other intrinsic subtleties, two of which were that (a) the F11F-1 was in Fleet service and, therefore, a redesign of the wing structure to improve drop tank-speed capability would be impractical and (b) any redesign of the store station or pylon attachments could not interfere with its ability to carry and deliver other tactical loads.

Considering all the possible avenues of solution and their ramifications, an alternate 150-gal. external tank, illustrated in Fig. 1b, was flight tested. Unlike its area-ruled predecessor, the second tank was 2 ft. shorter, 27 lbs. lighter, and—most significant—had 41 per cent less moment of inertia in pitch and yaw in the full condition. The additional drag and resultant performance penalty attributed to these tanks were far outweighed by their satisfactory vibratory characteristics. The magnitude of improvement in terms of air speed was in excess of 200 knots. This lower inertia successor to the area-ruled tank design was also found to be free of any throttling-induced difficulties in the empty, partially full, and full tank conditions. Once again, as in the Flight Basic Configuration Program, high-speed flutter checks of the full tanks were limited only by the airplane's thrust, drag, and safety considerations associated with high-speed, low-altitude dives and recoveries.

Pilot Technique During Neutrally Damped Oscillations

The most important consideration during the entire drop tank flight flutter program was that the type of instability encountered was a sustained or neutrally damped oscillation rather than a divergent or explosive form of flutter. The experienced project test pilot was, therefore, able to cope with, and alleviate, any situation before it became catastrophic. The neutrally damped mode was suppressed by gradually decreasing air speed.

Early in the program it was discovered that high load factor abrupt pullouts were ineffective in damping a sustained oscillation. On the contrary, the amplitude was seen to increase after rapidly applying load factor (see Fig. 6). Abrupt application of the F11F-1's dive brakes more than tripled the vibratory amplitude. The situation was analogous to the angler with a Striper on his line—he wants to boat the catch as soon as possible, however, a trifle too much haste and the prize is lost.

In the partial fuel-climb attitude problem, speed

reduction was inherently easy to accomplish, provided that the dive recovery did not penetrate the nebulous 600 KEAS boundary by more than 20–25 knots. The full tanks' difficulties were usually experienced in diving flight, making speed reduction efforts more hazardous—that is, the dive angle of the F11F-1, like that of many other supersonic craft, makes it exceedingly difficult to perform a diving maneuver at a given altitude and air speed without exceeding the speed during the roundout of the dive. The duct spillage problem associated with the long external tanks ruled out rapid engine throttling.

In order to conduct the flight program safely, 25-knot air-speed increments were scheduled for penetrating unexplored regions; when a neutrally damped condition was excited, the project pilot simultaneously reduced power and eased back the control stick with the finesse and dexterity of a combined symphony maestro and heart surgeon.

Conclusions

The dependence of wing and store stability on inertial, structural, and aerodynamic variations has been emphasized by the F11F-1 150-gal. external tank flight flutter program. Recalling the flight experiences, the following conclusions are noteworthy:

(1) Test results from two different 150-gal. external tanks indicate that the design having lower pitching and yawing moments of inertia exhibited superior vibrational properties.

(2) The flutter speed could be affected adversely by a 2 per cent wing weight reduction afforded by a skin milling operation in the main wing panels; similarly, weight reductions altering the mass distribution of the wing, such as lightening wing tips or emptying internal wing tank fuel, can also be detrimental.

(3) Increasing the wing-to-tank effective stiffness by preloading pickup points and sway braces may increase the flutter speed. However, such methods are usually subject to torque variations in actual service and place an additional safety-of-flight responsibility in the hands of the mechanic.

(4) The installation of horizontal tail fins to a large store not only may stabilize the ejection trajectory but also are conducive to vibrational stability.

(5) Wing-tip ballasting and external support struts can raise a flutter speed at the expense of increased weight and complexity.

(6) A simple air speed or Mach Number limitation to restrict an airplane from a potential flutter problem may be inadequate. Remember,

(a) Abrupt engine throttling induced sustained oscillations of the wing and drop tank at speeds several hundred knots lower than the steady or accelerating flight flutter conditions.

(b) Maneuvering conditions have a bearing on the dynamic stability as illustrated by the partially full drop tank tests resulting in satisfactory damping up to speeds approaching 800 knots, whereas in climbs at 600 knots poor damping was evident.

(7) The effect of other stores such as Sidewinders at outboard wing stations was beneficial to both the full and partially full drop tank stability problems; however, once the outboard weapons are fired, the stability bonus is spent.

(8) Although the excitation of a flutter mode is best remedied by reducing air speed, any rapid application of normal load factor, abrupt speed brake actuation, or immediate engine throttling can aggravate before alleviating any vibratory problem.

(9) Experiencing flutter in a high-speed dive usually involves an inadvertent excursion into still higher air speed prior to rounding out of the dive; therefore, the low-altitude, high dynamic pressure portion of an airplane's flight envelope should be substantiated prior to performing high Mach Number dives. The test pilot has more potential control over a flutter problem at a given air speed, if discovered in straight and level flight or a shallow dive at low altitude, than he does in a rapid rate of descent dive from high altitude.

The results of the F11F-1 flight flutter investigation with external stores have attested to the importance of dynamic compatibility between airplane and store. Foresight and judicious evaluation can produce an efficient store configuration and optimum location when considered in the initial design of a high-performance aircraft. The field of inquiry should include for appraisal at least the following:

(1) The airplane's basic and secondary missions.

(2) The structural design of the wing and store retaining devices.

(3) The inertial parameters inherent in the store's design.

(4) The flow fields in the vicinity of the prospective stores locations within the airplane's maximum Mach Number-altitude range and all expected flight attitudes.

When the addition of a store is proposed later than the preliminary design phase, such as during flight-test status, compromise in store capability is likely to be more severe.

The preceding conclusions relating to the design aspects from the dynamic analysis viewpoint, and to flight flutter test philosophy of relatively large wing-mounted stores on high-speed aircraft, is pertinent to future wing-store flutter evaluations both prior to and during the flight-test stage.

✦ ✦ ✦

Part I, published in January, outlined "the physical and mathematical bases required for the solution of optimum trajectory problems on an initial value basis." Part II presents "the development of the more general optimum boost relations which treat aerodynamic effects."

Optimum Rocket Trajectories

Part II—Generalized Boost Analysis

Daniel O. Dommasch, AFIAS, and Roger L. Barron, AIAS

DODCO, Inc.

PART I, published in January, discussed the application of variational techniques to the solution of optimum trajectory problems on an initial value basis and presented, as an example, the development of the path function relations for a simplified optimum boost analysis.

Part II presents a generalization of the work of the first article, as well as the results obtained using digital computer techniques for step-by-step integration of the optimum equation set, starting from a given set of initial conditions. The equations developed—and the numerical techniques—have been fully checked out by several independent groups, and digital codes are available for both the LGP-30 computer and the Datatron 205 units. A complete performance map describing the optimum boost performance of an advanced type of vehicle is presented in this part.

To provide a completely valid analysis, all known influences on the trajectory have been considered, including aerodynamic lift and drag, as well as the forces required to maintain flight in a great circle plane fixed to the rotating earth. The ARDC standard atmosphere has been precisely simulated, the effects of gravitic potential change are included, and the kinematic equations and equations of motion are satisfied precisely without any assumptions as to small perturbations. The results presented are therefore precise and can be duplicated by flight of real systems having the characteristics shown.

Equations of Motion

For purposes of this generalized study, motion of the boosted rocket is assumed to take place in an earth great circle plane which rotates along with the earth so that navigational reference with ground stations is maintained. The equations for flight in the inertial space great circle considered in Part I are obtained by simply setting the quantity Ω (earth rotative speed with respect to a fixed set of stellar axes) equal to zero in the equations presented. In any case, the plane of motion is identified by the angle ϕ which it makes with the north polar axis, and the location within the plane is given in terms of the angle θ measured from the trace of the ϕ-plane on the equatorial plane (with θ taken as positive in the direction of motion of the vehicle) and the radial distance of the aircraft from the center of the earth, designated h_a.

If x is the direction of the vehicle velocity vector (either relative or absolute), z is taken as perpendicular to x, within the plane of motion, and y is perpendicular to both x and z, then the Eulerian* moving axis equations (see reference 26, Part I) define the inertial forces F_{xi}, F_{yi}, and F_{zi} which appear in the x, y, and z directions for fixed ϕ as

$$F_{xi} = -m\dot{V}_r + m\Omega^2 h_a \left[\sin^2\phi \sin\gamma - \cos^2\phi \cos\theta \sin(\theta - \gamma)\right] \quad (1)$$

$$F_{yi} = -2m\Omega V_r \cos\phi \sin(\theta - \gamma) - m\Omega^2 h_a \sin\phi \cos\phi \sin\theta \quad (2)$$

$$F_{zi} = mV_r(\dot{\theta} - \dot{\gamma}) + 2m\Omega V_r \sin\phi + m\Omega^2 h_a \left[\sin^2\phi \cos\gamma + \cos^2\phi \cos\theta \cos(\theta - \gamma)\right] \quad (3)$$

in which m is the vehicle mass, V_r its velocity relative to an earth having inertial rotation rate Ω, and γ the flight path angle between $\vec{V}_r$ and the local horizontal.

The technique described here has been thoroughly checked in the course of USAF contract investigations. Our indebtedness to Paul J. Belcher of the Aircraft Laboratory, WADC, is hereby acknowledged.

* These are not to be confused with the Euler necessary conditions and are in no way related to those conditions.

The kinematic angular rate $\dot{\theta}$ is expressible as

$$\dot{\theta} = (V_r \cos \gamma)/h_a \tag{4}$$

and we also have the kinematic relation that $\dot{h}_a = V_r \sin \gamma$.

Eqs. (1), (2), and (3) are the generalized inertial equations in the navigational earth great circle reference system. These are inertial response forces, not applied forces, and the introduction of the applied forces of weight, lift, thrust, and drag provides the equations of motion:

$$F_e \cos \alpha - m\dot{V}_r - D - mg \sin \gamma + m\Omega^2 h_a [\sin^2 \phi \sin \gamma - \cos^2 \phi \cos \theta \sin (\theta - \gamma)] = 0 \tag{5}$$

$$F_e \sin \alpha - mg \cos \gamma + L + mV_r(\dot{\theta} - \dot{\gamma}) + 2m\Omega V_r \sin \phi + m\Omega^2 h_a [\sin^2 \phi \cos \gamma + \cos^2 \phi \cos \theta \cos (\theta - \gamma)] = 0 \tag{6}$$

$$F_e \sin \beta - 2m\Omega V_r \cos \phi \sin (\theta - \gamma) - m\Omega^2 h_a \sin \phi \cos \phi \sin \theta = 0 \tag{7}$$

Eqs. (5), (6), and (7) apply to the most practical boost procedure since they demand flight within a plane fixed relative to launching and tracking stations. In the equations, F_e is taken to represent net developed engine thrust at the instantaneous altitude; α denotes the vehicle angle of attack (thrust-line inclination with respect to trajectory); L and D are total lift and drag forces, respectively; while β represents vehicle angle of sideslip, which (although small) cannot in general be zero for the case of $\phi = 0$. The local gravitic acceleration g is found from

$$g = g_0 (R_e/h_a)^2 \tag{8}$$

where g_0 is the potential at the surface of an assumed spherical earth of radius R_e.

Latitude ζ (measured north from the equator) may be found by integrating

$$\dot{\zeta} = (\dot{\theta} \cos \theta \cos \phi)/\cos \zeta = \dot{\theta} \cos \psi \tag{9}$$

and longitude ξ by quadrature of

$$\dot{\xi} = (\dot{\theta} \sin \phi)/\cos^2 \zeta = \dot{\theta} \sin \psi/\cos \zeta \tag{10}$$

θ and h_a are found by integrating the kinematic relations for $\dot{\theta}$ and $\dot{h}_a$. In Eqs. (9) and (10), ψ is the instantaneous heading or azimuth angle, measured clockwise from north.

Any optimum or arbitrary trajectory of a rocket vehicle must satisfy Eqs. (5) and (6), with the additional requirement that β is found from Eq. (7) for flight within the earth great circle. If inertial great circle boost should be contemplated, Eq. (7) is eliminated and (5) and (6) simplified by setting $\Omega = 0$ (and replacing V_r and γ by absolute quantities V_a and γ_1). However, launching directly into an inertial great circle from a location fixed to the earth cannot generally be considered since it requires the instantaneous attainment of relative speed equal and opposite to the local earth rotational velocity.

Variational Analysis

It was shown in Part I that the existence of α in Eqs. (5) and (6) renders the system pseudoholonomic; however, since dual solutions cannot exist in the same quadrant, a valid anholonomic solution of this set is obtainable both theoretically and numerically. To achieve this solution for optimum boost, we first recognize that a fixed burning time for any rocket vehicle defines the maximum performance envelope in terms of an integral of the class

$$h_a = \int_1^2 V_r \sin \gamma \, dt \tag{11}$$

which we seek to render stationary (maximize), subject to the condition that the balance equations—(5) and (6)—must be satisfied at all times. We note further that this integral involves boundary conditions on V_r and γ, both initially and finally.

Introducing the coupled equations—(5) and (6)—in the form of an anholonomic subsidiary condition, we evidently require a variable Lagrange multiplier λ (see Part I).

In accordance with the developments of Part I, Eq. (11) is restrained by Eqs. (5) and (6) by introducing the term

$$F = -F_{x_1} - F_e \cos \alpha + mg \sin \gamma + D$$

to the variational integrand, with the understanding that sin α is given by Eq. (6) in the form

$$\sin \alpha = [m/(aqS + F_e)]\{[g - (V_r^2/h_a)] \cos \gamma + \gamma \dot{V}_r - \Omega^2 h_a [\sin^2 \phi \cos \gamma + \cos^2 \phi \cos \theta \cos (\theta - \gamma)] - 2V_r \Omega \sin \phi\}$$

where the term aqS is introduced by virtue of the circulation theory of lift which requires that $L = aqS \sin \alpha$, where a is the slope of the body lift curve.

Our problem is therefore to maximize the integral

$$J = \int_1^2 (V_r \sin \gamma + \lambda F) dt$$

For convenience $(V_r \sin \gamma + \lambda F)$ is designated as G in the further developments. Proceeding as in Part I, we find that

$$\dot{\lambda} = (1/m)(\partial G/\partial V_r - \lambda \dot{m}) \tag{12}$$

where

$$\frac{\partial G}{\partial V_r} = \sin \gamma + \lambda \left[\frac{\partial \alpha}{\partial V_r} (F_e \sin \alpha + 2KC_L aqS \cos \alpha) + \frac{2D}{V_r} + \frac{qs}{c_a} \left(\frac{\partial C_{D_e}}{\partial M} + C_L^2 \frac{\partial K}{\partial M} + 2KC_L \sin \alpha \frac{\partial a}{\partial M} \right) \right] \tag{13}$$

and $C_D = C_{D_e} + KC_L^2$, while

$$\frac{\partial \alpha}{\partial V_r} = A_1 \left[\frac{(\dot{\gamma} - 2\dot{\theta}) - 2\Omega \sin \phi}{\cos \alpha} - \frac{S}{m} \left(\rho a V_r + \frac{q \partial_a / \partial M}{c_a} \right) \tan \alpha \right] \quad (14)$$

$$A_1 = m/(aqS + F_e) \quad (15)$$

M in the above is Mach Number, given by $M = V_r/c_a$, in which c_a is the local speed of sound; q is dynamic pressure, $q = \rho V_r^2/2$; ρ is local atmosphere density; S is the wing or reference area; and $C_L = a \sin \alpha$ denotes lift coefficient of the vehicle. C_{D_e}, K, and a are parasite drag coefficient, induced drag factor, and lift-curve slope, respectively, and as such are functions of Mach Number. (K dependence on C_L may generally be ignored for these studies.)

Similarly, after some algebra we obtain the relation for $\ddot{\gamma}$

$$\ddot{\gamma} = [(\partial G/\partial \gamma - X_3)/(X_2 X_4)] - X_1/X_2 \quad (16)$$

for which the several parameters are given by

$$\partial G/\partial \gamma = V_r \cos \gamma + \lambda_1 + \lambda \{ m(g \cos \gamma - Y_1) + A_1 \sin \alpha \, [(F_e/\cos \alpha) + 2a^2 qSK] \, (Y_2 - A_2 \sin \gamma) \} \quad (17)$$

where λ_1 = "path shape" parameter (a constant multiplier introduced as a perimeter condition to avoid trivial solutions for starts at $\gamma = 90°$) and

$$A_2 = g - V_r^2/h_a \quad (18)$$

$$Y_1 = \Omega^2 h_a \, [\sin^2 \phi \cos \gamma + \cos^2 \phi \cos \theta \cos (\theta - \gamma)] \quad (19)$$

$$Y_2 = \Omega^2 h_a \, [\sin^2 \phi \sin \gamma - \cos^2 \phi \cos \theta \sin (\theta - \gamma)] \quad (20)$$

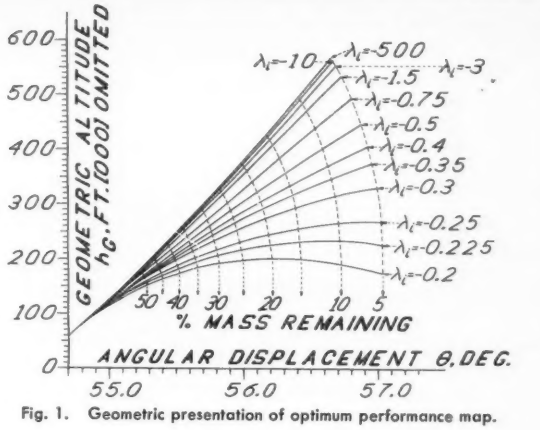

Fig. 1. Geometric presentation of optimum performance map.

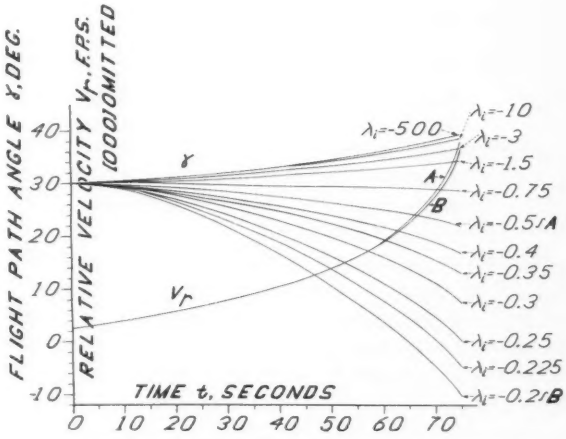

Fig. 2. Kinematic presentation of optimum performance map.

$$X_1 = \tan \alpha \left[\frac{\dot{m}}{m} - \frac{qS(\dot{a} + a\dot{q}/q) + F_e}{aqS + F_e} \right] + \frac{A_1}{\cos \alpha} \left\{ \left[\dot{g} + \frac{V_r^2}{h_a} \left(\frac{\dot{h}_a}{h_a} - 2 \frac{\dot{V}_r}{V_r} \right) \right] \cos \gamma - Y_1 (\dot{h}_a/h_a) + \dot{\gamma}(\dot{V}_r + Y_2 - A_2 \sin \gamma) - 2\dot{V}_r \Omega \sin \phi + \dot{\theta} \Omega^2 h_a \cos^2 \phi \sin (2\theta - \gamma) \right\} \quad (21)$$

$$D = qS(C_{D_e} + KC_L^2) \quad (22)$$

$$\dot{q}/q = 2\{(\dot{V}_r/V_r) + [(\partial \rho/\partial h)/\rho] \cdot (h' \dot{h}_a/2)\} \quad (23)$$

where h = geopotential altitude, $h' = dh/dh_a$

$$X_2 = A_1 V_r/\cos \alpha \quad (24)$$

$$X_3 = \frac{\partial G}{\partial \dot{\gamma}} \left[\frac{\dot{\lambda}}{\lambda} + \frac{\dot{m}}{m} + \frac{\dot{V}_r}{V_r} + \frac{qS(\dot{a} + a\dot{q}/q) + \dot{F}_e}{aqS + F_e} \right] + A_3 \left[\frac{\dot{F}_e}{\cos \alpha} + 2a^2 qSK \left(\frac{2\dot{a}}{a} + \frac{\dot{q}}{q} + \frac{\dot{K}}{K} \right) \right] \quad (25)$$

$$A_3 = A_1 \lambda V_r \sin \alpha \quad (26)$$

$$\partial G/\partial \dot{\gamma} = A_3[(F_e/\cos \alpha) + 2a^2 qSK] \quad (27)$$

$$X_4 = [(\partial G/\partial \dot{\gamma})/\tan \alpha] + [A_3 F_e/(\cos \alpha \cot \alpha)] \quad (28)$$

Eqs. (12) through (28) define the variational optimum path function. These may be employed in an appropriate digital computer program which also incorporates data handling provisions for the various vehicle parameters as functions of time, speed, and altitude and which integrates the equation set, including the kinematic equations and equations of motion, on a step-by-step basis from specified initial conditions for any given initial value of λ.

The kinematic equations utilized for solution on a first and second derivative level are

$$\dot{h}_a = V_r \sin \gamma \quad (29)$$

$$\ddot{h}_a = \dot{V}_r \sin \gamma + \dot{\gamma} V_r \cos \gamma \quad (30)$$

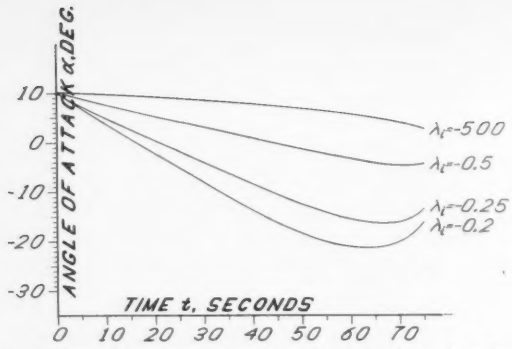

Fig. 3. History of thrust angle of attack variations for the paths of Figs. 1 and 2.

$$\dot{\theta} = V_r \cos \gamma / h_a \quad (31)$$

$$\ddot{\theta} = \dot{\theta}[(\dot{V}_r/V_r) - (\dot{\gamma} \tan \gamma) - (\dot{h}_a/h_a)] \quad (32)$$

The equations of motion provide

$$\dot{V}_r = Y_2 + [(1/m)(F_e \cos \alpha - D)] - g \sin \gamma \quad (33)$$

$$\sin \alpha = A_1(A_2 \cos \gamma + \dot{\gamma} V_r - 2V_r \Omega \sin \phi - Y_1) \quad (34)$$

As mentioned in Part I, $\dot{m}$ and $\dot{F}_e$ are specified design values, and computational accuracy is improved by using the time derivative of Eq. (33) when Taylor series integration is employed.

In our computations a program precisely simulating the ARDC standard atmosphere was employed based on the data presented in AFCRC TN-56-204. Since numerous such programs are available throughout the industry, the equations used need not be presented here.

Numerical Results

To provide numerical data for this article, computer studies of a hypothetical vehicle have been conducted using DODCO's Dictator programing system in conjunction with LGP-30 computing machines. This series of runs using the optimum rocket trajectory program (entitled Deoca) has been given the characteristics of the following hypothetical rocket vehicle:

Initial weight (at sea level), 10,000 lbs.
Minimum terminal weight (at sea level), 500 lbs.
Maximum burning time, 75.0 sec.
Sea-level thrust, 39,535.2 lbs.
Thrust in vacuum, 48,000.0 lbs.
Mass flow rate, 3,936,920.5 slugs/sec.
Reference area, 8.0 ft.^{2}
Sea-level specific impulse, 312.12 sec.

Reasonable C_{D_e}, K, and a values have been postulated in addition to the above, and approximately 12 digital computer solutions have been obtained for a wide spectrum of initial λ values (with the parameter $\lambda_1 = 0$). The following set of launch conditions has been selected:

$M = 2.5$
$h_G = 60{,}000$ ft. (geometric altitude)
$\gamma = 30°$
$\dot{\gamma} = 0$ (implies $\alpha = 10.2819°$)
$\zeta = 45°$
$\psi = 45°$
$R_e = 20{,}890{,}874.8$ ft.

The vehicle configuration and launch conditions have been tailored to an air-launch mission designed to "seed" large regions at the upper reaches of the atmosphere with a high density of foreign particles (such as sand, buckshot, etc.). It is assumed that the rocket payload includes explosive charges for dispersing the foreign material either upon burnout of the missile or after a preset coasting period. The data used in the study do not represent any specific weapon system but are felt to be indicative of present advanced state of the art in missile development. The optimum performance results obtained here serve as an abbreviated optimum operations analysis for a projected defense against semi-orbital equipment, including long-range missiles traveling at great speed and altitude.

The techniques used in this numerical work have been those of optimum-performance "mapping." Evidently, for given initial conditions, the trajectory defined by the optimum equations is dependent on the initial value specified for the variable Lagrange multiplier. The implications of this fact are best appreciated by reference to Fig. 1, presenting a family of curves for geometric altitude h_G vs. geographic location θ within the earth great circle ϕ-plane. (Note in this connection that one degree of θ corresponds to approximately 60 nautical miles along the earth surface.)

It is clear from Fig. 1 that an infinite subclass of optimum-performance terminal conditions may be reached by the postulated configuration and that the sole parameter which need be altered to produce a change in trajectory is the initial λ value.* Thus curves have been obtained which display either a terminal "zoom" or a terminal dive behavior, as well as paths terminating in a level flight condition ($\gamma = 0$). Since the payload magnitude may be a quantity at the discretion of the analyst, a cross-plot of various mass ratios is shown to indicate the terminal conditions which may be reached for any specified ratio of final mass (at burnout) to initial mass.

Figs. 1, 2, and 3 provide a complete set of data describing the series of runs conducted to provide numerical data for this article.

Conclusion

This paper has presented the mathematical and physical concepts which define the optimum trajectories of high-performance rocket vehicles (boosted within or out of the atmosphere and in either the inertial great circle or the navigational, earth great circle plane) and has described briefly the results of computer studies based on a hypothetical (but typical) missile system. The results obtained indicate, we feel, the power and scope of optimum methodology when applied to advanced dynamic performance problem areas.

* Note that the shaping parameter λ_1 is set equal to zero for these studies since no additional restraint is required to avoid the trivial optimum of $\gamma = 90°$.

In Part I the high-thrust nuclear system was discussed in the performance of the Martian mission, while Part II is devoted to the low-thrust electrical propulsion system. Part II also includes a review comparison of the high- and low-thrust systems.

Manned Nuclear Space Systems

Part II—Low-Thrust Nuclear Systems

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NUCLEAR REACTORS are certain to play a large role in future exploration and exploitation of space. Part I of this paper discussed high-thrust space systems utilizing nuclear heat sources and a hydrogen working fluid.[1] Performance investigations indicated that attractive round-trip Martian missions, on the order of 1 year in duration, could be accomplished with single-stage vehicles at specific impulses I_{sp} of 2,000 sec. or at I_{sp}'s of about 1,200 sec. if refueling at Mars is possible. A two-stage Martian vehicle was sized with $I_{sp} = 1{,}000$ sec. and $\lambda' = 0.9$ (λ' is the ratio of fuel weight to total propulsion system weight). The mission involved Earth surface to Martian orbit transfer and return with refueling at Mars from three tanker vehicles which traveled a lower energy trajectory.

Shielding methods and permissible radiological exposures to acute radiations were discussed, and it was noted that total exposures of 12 rem (the new maximum permissible yearly dose) are reasonable and yield scatter shield weights on the order of 2 per cent of vehicle gross weight (25 per cent of the payload weight). The direct radiations were attenuated by fuel and ecological materials.

This part of the paper will cover low-thrust space vehicles and their application to similar Martian missions. An attempt is made to outline the areas of utilization of the low-thrust vehicle in relation to the high-thrust vehicle.

Missions

Numerous sources are available in the literature discussing low-thrust nuclear space vehicles.[2–5] These sources collect into two general areas on the specific weight of the energy source—i.e., 10 lbs./kw. and 25 lbs./kw., with few sources supporting lower values. Considering the efficiency of the turbine, the generator, and the accelerator itself, the area between 10 lbs./kw. and 25 lbs./kw. may be assumed to be reasonably optimistic since it implies only 1 to 5 lbs./kw. for the reactor. The thrust available per pound of energy source will be in the range $1\text{–}4 \times 10^{-4}$ lbs./lb. Vehicle accelerations will then be less than $1\text{–}4 \times 10^{-4}\ g$ depending upon velocity requirements and payload. Velocity requirements for Martian missions are indicated in Fig. 1 as a function of total travel time for the mission.

Utilization of low acceleration systems introduces a velocity penalty in escape from gravitational fields. Fig. 2 indicates the total impulsive velocity requirement to escape from a low-altitude circular orbit about Earth to various hyperbolic excess velocities. Note that this kinematic inefficiency does not exist for large-thrust vehicles. The total velocity required for vehicles with thrust-to-mass ratio on the order of 10^{-4} g is about twice the requirement for large thrust-to-mass systems.

It is of interest to examine the low-thrust vehicle which would accomplish the mission considered in

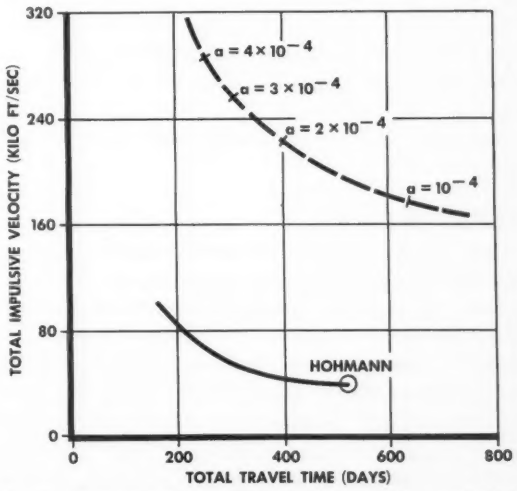

Fig. 1. Mars round trip. Total impulsive velocity required—low Earth orbit to low Martian orbit and return to low Earth orbit. (——— high thrust; — — — low thrust.)

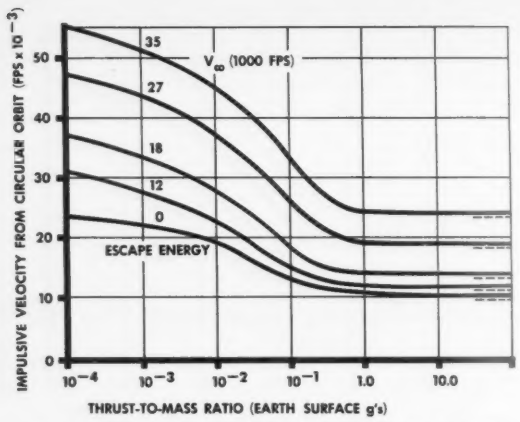

Fig. 2. Total impulsive velocity escape from circular orbit.

Part I in the same total travel time. It is first assumed that the four boosters used in Part I place a total payload of 956,000 lbs. in low-altitude Earth orbit. This payload will be used as the low-thrust vehicle initial weight. A total propulsion time of 371 days will require 233,000 ft./sec. of impulsive velocity to accomplish the round-trip mission. Assuming that the total mission requires 3 years for completion and that a nonregenerative ecological system would be used as in the high-thrust system, then the payload would increase from 55,000 to 85,000 lbs. The specific weight of the energy source required to accomplish this mission is about 7.5 lbs./kw. Engine, propellant, structure, shielding, and payload weights were considered in this determination.

Higher values of specific weight become useful for longer missions. If a low-thrust vehicle is compared with the mission of the three large-thrust tanker vehicles rather than in accomplishment of the entire large-thrust mission, the refueling trips can be accomplished over a longer time span, say 1 year. The gross weight in orbit for this mission is 717,000 lbs., and it is required that 244,000 lbs. of propellant be delivered to Mars. The velocity requirement for this mission is about 85,000 ft./sec. impulsive velocity. This mission can be accomplished with a specific weight of energy source equal to about 20 lbs./kw. Longer missions can conceivably be accomplished for supply transport to Martian orbit with larger specific weight sources.

Radiological Aspects

In the high-thrust nuclear system the primary radiation problem for the crew was short-term, acute exposure, while the low-thrust ionic system involves long-term, chronic radiation. The consequences of chronic lifetime exposure to radiation are not as clear as those from instantaneous or short-term exposure to total body radiation. There is evidence, however, that long-term damage can be assessed largely in terms of decreased life span. Shields Warren[6] indicates that the longevity of American radiologists in comparison to unexposed physicians is less by an average of 5.2 years, the average ages of death being 60.5 and 65.7 years, respectively.

Available data indicate that sublethal irradiation of the whole body causes premature death primarily by accelerating the actual biological aging process.[7] For the aging effect the fractional reduction in life span per roentgen may not be as great for exposure at low intensity over long periods of time as compared with a single exposure of the same total dose.[8] In general, for given dose rates, the survival time is inversely related to the amount of radiation energy absorbed. The amount of life shortening is generally more if a given total dose is absorbed in a short period of time—i.e., to an acute radiation exposure. As an example, workers exposed to the old maximum permissible AEC dose rate of 0.3 r/week (15 r/year) would receive a dose of 450 r in 30 years and presumably show no visible signs of damage. However, the same dose of 450/r received as whole body acute radiation would probably be fatal to 50 per cent of the exposed persons.

The statistical life shortening per rem of radiation is believed to be about 5 to 10 days. If this is true, then the statistical average life shortening probability for the new recommended maximum permissible lifetime exposure of 225 rem would be no greater than 3 to 6 years. Langham notes: "Whereas 225 r of whole-body gamma radiation may shorten the average life expectancy of a large population by about 3–6 years, it cannot be said that the life of any specific individual in the population will be shortened by that amount."[9]

Henshaw[10] summarizes the effects of near lethal dose short duration exposure as follows: (1) there is an immediate condition of sickness or shock, (2) the degree of illness varies directly with dose, (3) the illness may be less during the second to fourth or fifth days, (4) during the second and third weeks there is a precipitous fall in fitness which coincides with the cascade of tissue necrosis, and (5) during the fourth week, recovery commences, which then for certain organs (gastrointestinal and hemopoietic which in particular are of vital importance) reaches the normal range in 2 to 4 months.

Henshaw states: "In protracted or intermittent exposure performance ability changes at different times in connection with daily treatment of different amounts. A shock response is totally absent due to any dramatic

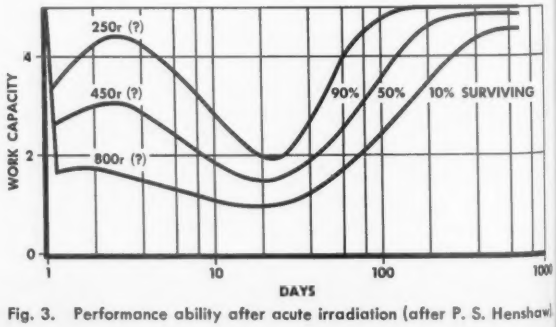

Fig. 3. Performance ability after acute irradiation (after P. S. Henshaw)

effects at the beginning, but work capacity falls with accumulation of the integrated effects. For doses of 20 r per day, work capacity becomes noticeably reduced in 2 to 3 weeks with death occurring as an end result at about 2 months. Reduction in work capacity is barely noticeable in 3 months for doses of 5 r per day, but that it does fall gradually, with death occurring in 3 to 4 years. There is no noticeable reduction in work capacity for doses of 1 r per day in 3 years' time." The latter might be compared to a Martian mission by ion propulsion.

The effects of acute and chronic exposure on performance ability-work capacity are shown in Figs. 3 and 4, respectively. To obtain these graphs Henshaw used a performance scale from 5 downward, based on clinical hemotological and histopathological information. The descriptive terms that he used to represent different levels of work capacity or illness are as follows:

(5) Reserve energy—ability to do a 10-mile march.
(4) Normal work—ability to perform a regular day's work.
(3) Lassitude and easy fatigue.
(2) Illness (sickness, discomfort, anxiety) but capable of self-care.
(1) Illness, but with need of nursing care.
(0) Death.

Blair concludes that "a limit of 200 roentgen for emergency exposures for any period up to 30 days will not entail acute lethality or significant incapacity." Consequently, life shortening would be as much as 6 per cent, about 4 years, if man is like the rodent (the test specimen) and if the dose is received over a short period. If the dose is less than a given amount, possibly about 100 r on any one day, life shortening will be about 2 per cent. However, there are no definite data for any species on how small the daily level must be to cause the lesser effect.[11]

Observations by Blair on rodents indicate that life is shortened about 7 per cent per LD_{50} or by doses whose daily components do not exceed 120 r. The effect with doses administered in less than a few hours is about 3 per cent per 100 r in the 200 to 500 r range and is greater with larger doses. This difference is not attributable to dose rate per se but to total dose within a given time. In the rat 600 r in one day shortened the life span some 20 per cent, but given in ten daily doses of 60 r, a much smaller effect is obtained.

Cells are killed or modified by induction of biochemical changes and/or mutations (a very specific kind of biochemical change) following irradiation. Life shortening is probably produced by the same means since biochemical and mutational changes appear to be the main means by which radiobiologic changes are induced. Mutational changes are the most likely radiobiologic change that provides a line between irradiation and premature death which occurs months or years later. This theory provides a plausible basis for explaining radiation life shortening and, at the same time, what is identified as a third type of erosive action. Radiation

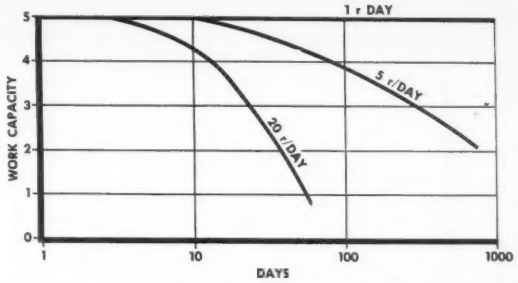

Fig. 4. Performance ability after intermittent or protracted exposure (after P. S. Henshaw).

produces mutations in proliferating cells, but certain of the induced types are sublethal. Therefore, these are able to continue with proliferation. Most of the mutations that persist are of the deleterious type involving reduced cellular efficiency and leading to reduced organ and organism efficiency. There then exists a means not only for the persistence of irradiation effects throughout life but also for degenerative changes to lead to earlier times of death. The net effect over time is a gradual tissue reduced efficiency. Death is the natural consequence when tissue transformation reaches a point of organ failure in a vital part.[10]

Besides the decreased life expectancy some of the chronic radiation (delayed) effects include cataract of the lens of the eye, platic anemia, increased incidence of malignant disease (i.e., leukemia) and increased incidence of genetic changes.[9] Therefore, it is considered wise to limit the dose to AEC tolerance levels in the low-thrust calculations, as was done for the high-thrust system in Part I.[1]

Radiation Environment and Shielding

Part I of this paper discusses the radiation environment from reactor radiations as do some previous works.[1,12] On the order of 0.6 per cent of the reactor power leaks out in the form of the radiation environment. It is to be expected that similar radiation leakages will be encountered on nuclear electric systems as the reactors will be designed as fast reactors with maximum power density. The radiation environment will primarily involve high energy neutrons and gamma radiation.

Radiation environment from the Van Allen belts is somewhat different in that the dose rates are from high energy protons. Transit through the inner belt may yield a dose of 2–10 rem. The high energy particles may be stopped by material also used for structure or sustenance. In determining the radiation environment in detail, shield estimates will have to be examined in light of secondary radiations. Since unshielded radiation intensities in the inner belt may be as high as 100 rem/hour man will most certainly require shielding while performing extravehicular functions. The outer Van Allen belt exhibits an equally dangerous unshielded environment from electron fluxes; these radiations are removed, however, by modest shields.

The solar flares and corpuscular streams are the least

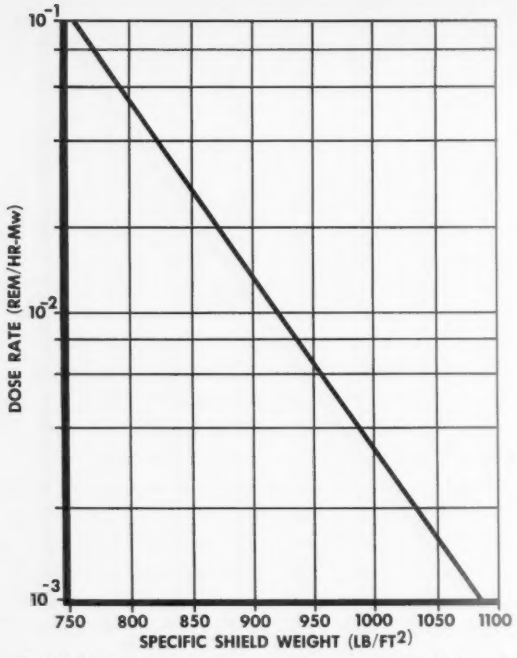

Fig. 5. Shielded reactor dose rate at 5 ft. LiH + U^{238} shield material.

understood and perhaps the most dangerous of the space radiations. It was only recently recognized that solar-emitted radiation bursts and corpuscular streams may cause intense radiations of very high energy particles. These radiations may cause biological and shielding problems in both the high- and low-thrust nuclear vehicle space flights.

Solar flares are probably the most dangerous to man. The emission of energetic protons during a flare could result in dose rates as high as 1,000 roentgen per hour in outer space (above 14 Earth radii). The particules are believed to be in the hundreds of Mev range, occurring without warning and in no particular pattern that can be determined at this state of our knowledge. In the corpuscular streams the dose rate may be higher than the flares, but the energies are lower. Shielding against the streams should be much simpler than against the flares. Streams are preceded by the more dangerous flare so that detection and protection against the flare will give warning against the possible arrival of a stream.

Usually, the flare activity follows very closely the sunspot activity. However, there have been many solar bursts of intense radiation which have occurred during minimum sunspot activity. Although some correlation exists between sunspot activity and solar flare frequency, no definite theory can be postulated until satellites have explored the flare phenomena during minimum sunspot numbers—i.e., approximately 5 years away.

In Part I of this paper, where protection from the acute radiations during operation of the reactor and from the shutdown reactor was discussed, a fixed shield was maintained about the crew well which could provide protection from solar and other space radiations. Ecological materials were used, where economical, to replace shielding. In analysis of low-thrust systems utilized from orbit, it is convenient to use only a shadow shield in protection from the reactor radiations as there will be no atmosphere scattering. This will require placing no structure outside the shielded shadow angle. Such structure would scatter some radiation toward the crew compartment. Fig. 5 can be used to determine the shield requirements for personnel protection given input data of permissible dose rate, reactor thermal power, area over which shield is to be applied, and reactor to crew separation distance. The included figure is for one thermal megawatt, and 5 ft. of separation.

Ecological materials at the crew compartment will naturally provide some additional shielding, but a pure shadow shield at the crew compartment would be large in area and therefore heavy. The required shadow angle must, again, enclose such items as the thermal radiator. If crew members are to venture outside the space vehicle at any time while in transit, the shadow shield at the reactor offers the greatest protection.

While it may be difficult to utilize adequately the ecological materials in reactor shielding, they can still perform a secondary function. Protection must be supplied for the crew from extreme space radiation occurrences such as solar flares. Ecological materials can again shield a given volume provided for space crew protection under extreme radiologic hazard. It is true that these hazardous circumstances are not yet well known but available data indicate that shielding of the order of 20 lbs. of sustenance material ft.^{2} of area to be shielded may be adequate. This would indicate that sustenance for a three man-three year mission, as investigated earlier, might protect a cylindrical volume with height 23 ft. and diameter 23 ft. This indicates little limitation upon required volume for manned travel.

Payload Capability

Part I of this paper had a distribution of the 55,000 lb. payload weight of the macronuclear system. The sustenance material for the three-man crew at 15 lbs. man/day for the 421-day Martian mission was 19,00 lbs. If the microthrust vehicle could perform the same mission, the payload would have to be the same using a nonregenerative ecological system. Since the vital payload would not be required as protection against the direct radiations from the nuclear reactor in the low thrust system then this material could be used to shield the crew from the space radiations. However as mentioned earlier, a rapid round-trip mission to Mar equivalent to the high-thrust system is not considered feasible within the present or projected state of the art. At a highly optimistic 7.5 lbs./kw. the total mission time would require about 3 years. The payload for this system would be 85,000 lbs. This would include a completely nonregenerative ecological system at about 49,00 lbs. It should be pointed out that this ecological require

ment can be significantly reduced by the use of partially regenerative systems. A recent study describes the design of an operational ecological system.[12] It is possible and desirable to integrate the thermal and atmospheric control systems as can be seen in Fig. 6.

The atmospheric cooling in the crew compartment would be accomplished by circulating air through plastic ducts connected directly to the space cabin structure—i.e., the radiator panel. Fig. 6 shows a sketch of the system. Humidity control is accomplished by condensation of water vapor from the air on the cool, 40°F., radiator surface. Cool air exhausting from the radiator at 50°F. and a relative humidity of 100 per cent warms to 70°F. and a relative humidity of 50° per cent. To accomplish the collection of water vapor condensed on the radiator panels in the subgravity or weightless state a mechanical system would be employed. First, the water drops are blown by air flow to the exit of the radiator panel. This is assuredly due to the fact that the radiator panel is covered with a material which will not be penetrated by water; therefore, the drops stand high and are easily moved by the airflow. Second, the water must be taken from the main airflow system. This is accomplished by the use of a water and air bleed at the sharp bend shown in Fig. 6. The sharp bend is necessary to utilize momentum effects to collect condensed water vapor which may be entrained in the air system. Finally, the water and air mixture taken from the bend must be separated. A simple centrifugal separator is used in connection with a water filter and collected in a rubber storage tank to give potable water for use by the crew. By this method 2.2 lbs. of water/man/day are returned to the water system by collecting and purifying the respiration and perspiration liberated by the astronauts. The remainder of the waste water, primarily urine, can be purified to a potable state by the use of a urine distillation system which utilizes a centrifugal boiler and a similar condenser panel as described for the atmosphere cooling system.

The use of the above-mentioned water recycling system would reduce the sustenance requirement from 15 lbs./man/day to about 9 lbs./man/day. Additional water could be saved by the use of a regenerative CO_2 absorber. Present work in progress indicates the feasibility of using the structural radiation panel concept—i.e., the passive thermodynamic environmental control where values of emissivity E and absorptivity α are determined to attain the desired radiator panel temperatures low enough to freeze out from the air not only water but also CO_2. Since it is doubtful that the crew could (or would want to) exist on nothing but an algal diet, the balanced (completely regenerative) ecological system does not appear to be attractive. If an algal gas exchanger is perfected in the future, it could be used in a partially regenerative scheme with food at 2 lbs./man/day being carried from Earth. This would provide at least some sustenance material to be utilized as a radiation shield against solar flares, corpuscular streams,

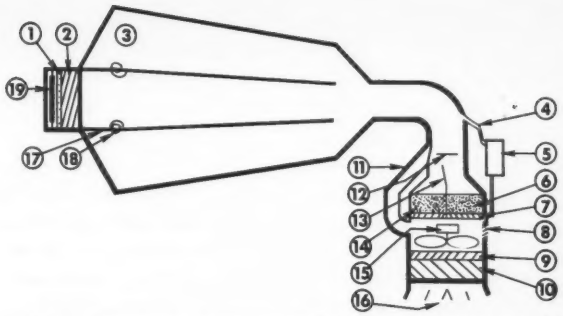

Fig. 6. Temperature environment control system: (1) intake grill, (2) electrostatic filter, (3) radiator panel, (4) condensed water bleed, (5) centrifugal water-air separator, (6) LiOH bed, (7) glass wool filter, (8) recirculation air control, (9) glass wool filter, (10) activated charcoal bed, (11) by-pass duct, (12) coburner, (13) flow distribution control, (14) KO_2 bed, (15) variable speed motor and fan, (16) exit diffuser, (17) flow distribution control, (18) bimetal strip for activation of 17, (19) UV light.

and Van Allen belts. The algal system is relatively complex due to the biological aspects and the problem of obtaining high reliability with such a system. It must operate continuously for over 3 years which would be extremely difficult; whereas, in the partially regenerative, passive thermodynamic, atmospheric cooling and water recycling system mentioned above, the only critical component is a heavy-duty, electric fan-motor unit. Because of the light weight of this component, additional back-up motors could be provided to operate a 3-year mission.

In the mission section it was noted that higher values of specific weight became useful for longer low-thrust missions and that 244,000 lbs. of payload could be delivered to Mars with a specific weight of energy source being equal to 20 lbs./kw. With this larger payload capability and actual longer operating times, it should not be too difficult to justify a nonregenerative ecological system since material could be used as a protection shield against space radiations. The assumed shield weight required for protection against space radiations is about 20 lbs./sq.ft. This means that 50,000 lbs. of sustenance should be able to cover 2,500 sq.ft.—i.e., a sizable compartment. As was pointed out an ion vehicle with a capability of 244,000 lbs. of payload could be used as a logistics carrier primarily to deliver propellant to Mars for the high-thrust systems. It is not clear at this time that a crew would be required on the ionic vehicle during its long flight times since crews in high-thrust systems might be able to monitor adequately the progress of the low-thrust systems.

System Comparison

The foregoing analyses have indicated several of the favorable features of both macro- and microthrust vehicles. Those features included herein are by no means all inclusive; such features as reliability, lifetime and reusability of engines have not been discussed. Briefly, reliability of an engine is based on the successful testing time of the engine relative to the operational time. For low-thrust engines, good reliability may require several hundreds of years of testing time or several hundreds of tests, each of about a year's dura-

tion. High-thrust engines may require less than one week of total test time in determination of reliability. In the case of manned operations to Mars, the shorter round-trip times have several advantages. One is the increased reliability of the ecological system due to the decrease in continuous operating time. The decreased flight time also reduces the probability of suffering the effects of one or more of the hazards—for example, space radiations (Van Allen belts, solar flares, corpuscular streams), meteoroidal damage, communication and/or navigation equipment failure, boredom.

Thermal, electrical, and kinematic inefficiencies require a low-thrust system to utilize several orders of magnitude greater energy than high-thrust systems in accomplishing the same mission. This large energy requirement leads to the burnup of uranium roughly equivalent to the critical mass of anticipated reactors for nuclear electric systems while accomplishing only one mission. Difficult reactor design problems are thus envisioned. However, the large-thrust engines will not encounter this design difficulty. It may well be that reactors for low-thrust missions will not be designed for reusability whereas reactors for large-thrust vehicles may find this an attractive, though difficult, design feature.

A possible major disadvantage of the ion vehicle is that the whole massive system must be boosted, assembled, and checked out in orbit. This will require the maintenance of a rather extensive and expensive orbital space station(s) capability.

The ability of high-thrust and low-thrust systems to perform Martian missions has been investigated and it appears the high-thrust systems are quite applicable to short mission times, whereas the low-thrust systems lean toward longer trip times and large payloads. These preferences indicate that macrothrust vehicles may well carry man on missions such as that sized in Part I and microthrust vehicles may best be used as refueling tankers or supply vehicles on low energy transfer of large payloads. These conclusions are, in part, based upon the fact that ecologically and physiologically man would prefer to spend a minimum of time in transit. Shielding does not have a serious effect on either system even though low-thrust systems require larger total energies. This lack of shielding differential lies chiefly in the logarithmic attenuation of radiation.

An often overlooked feature of large-thrust systems that lies lurking in the background is the booster capability. Each of the missions analyzed here, for example, assumes a nuclear boost. Low-thrust systems are, of course, incapable of supplying this boost, and chemical systems are the poor performance brother of nuclear systems. It is thus anticipated that high-thrust nuclear rockets will be in a position where boosting and single-stage missions are essentially in its domain and they will be the leading contender in many space missions. Low-thrust systems, while they will be developed concurrently with the nuclear rocket, can expect to serve in attitude stabilization and in the supply of electrical energy to the spaceship—that is, from the nuclear electric source—but the interplanetary propulsive role is less clear. The key to the utilization of low-thrust systems is the specific weight of the energy source. With specific weights of less than 20 lbs./kw., low-thrust systems enter into competition for unmanned interplanetary cargo missions where short time is not a prime requirement. With specific weights of less than 10 lbs./kw., low-thrust systems enter into the regime of feasible manned interplanetary missions although, at least for transit to the minor planets, mission time requirements are still large.

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AERO/SPACE Reviews

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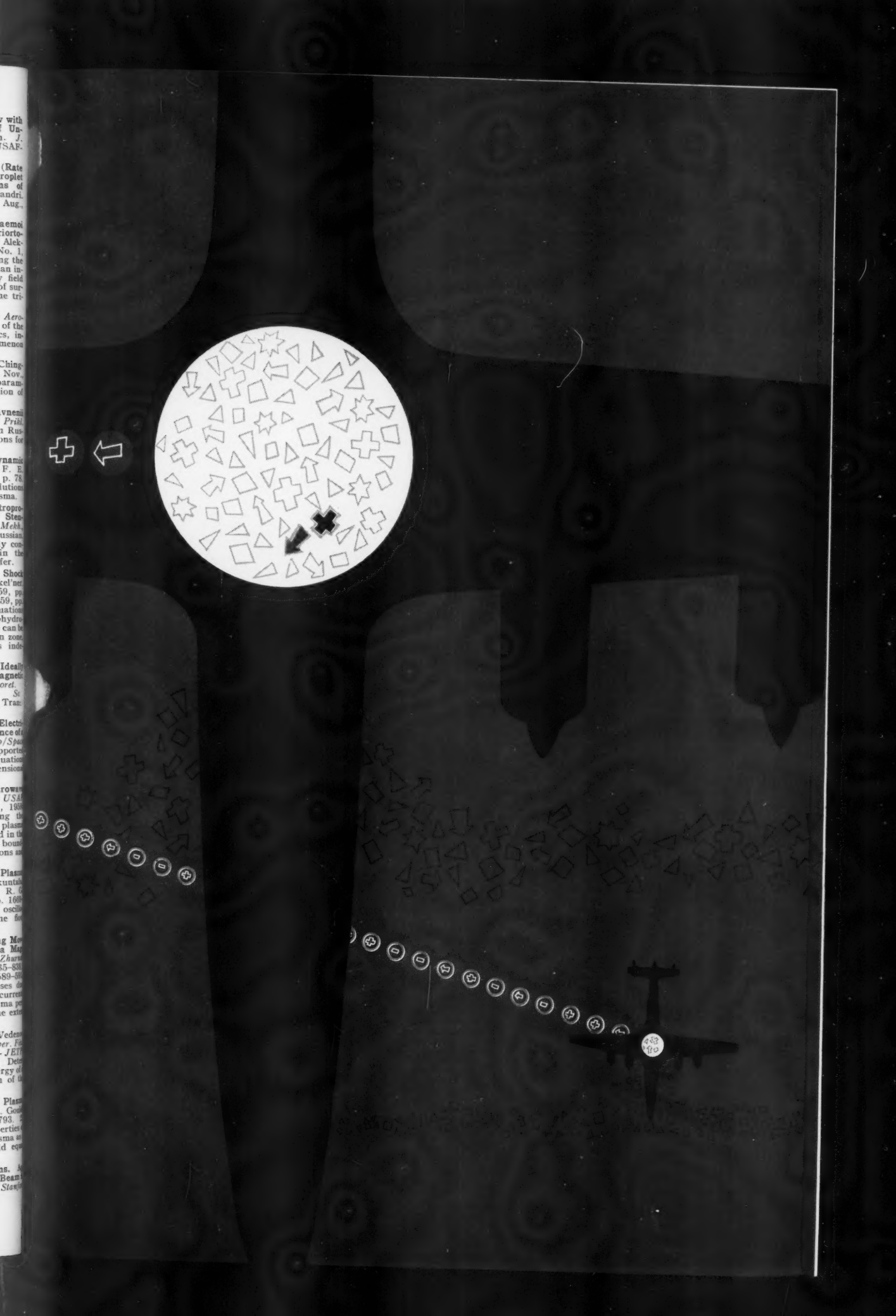

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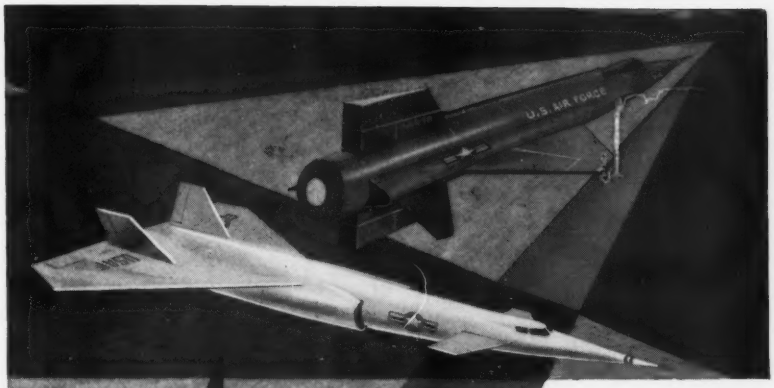

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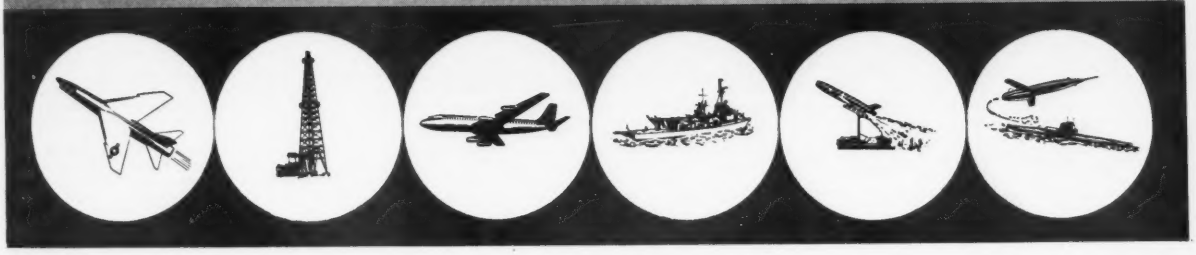

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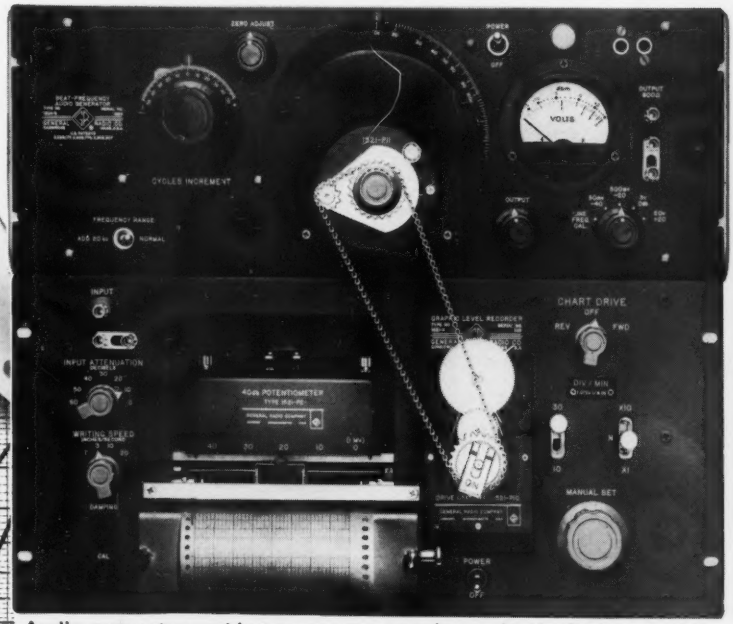

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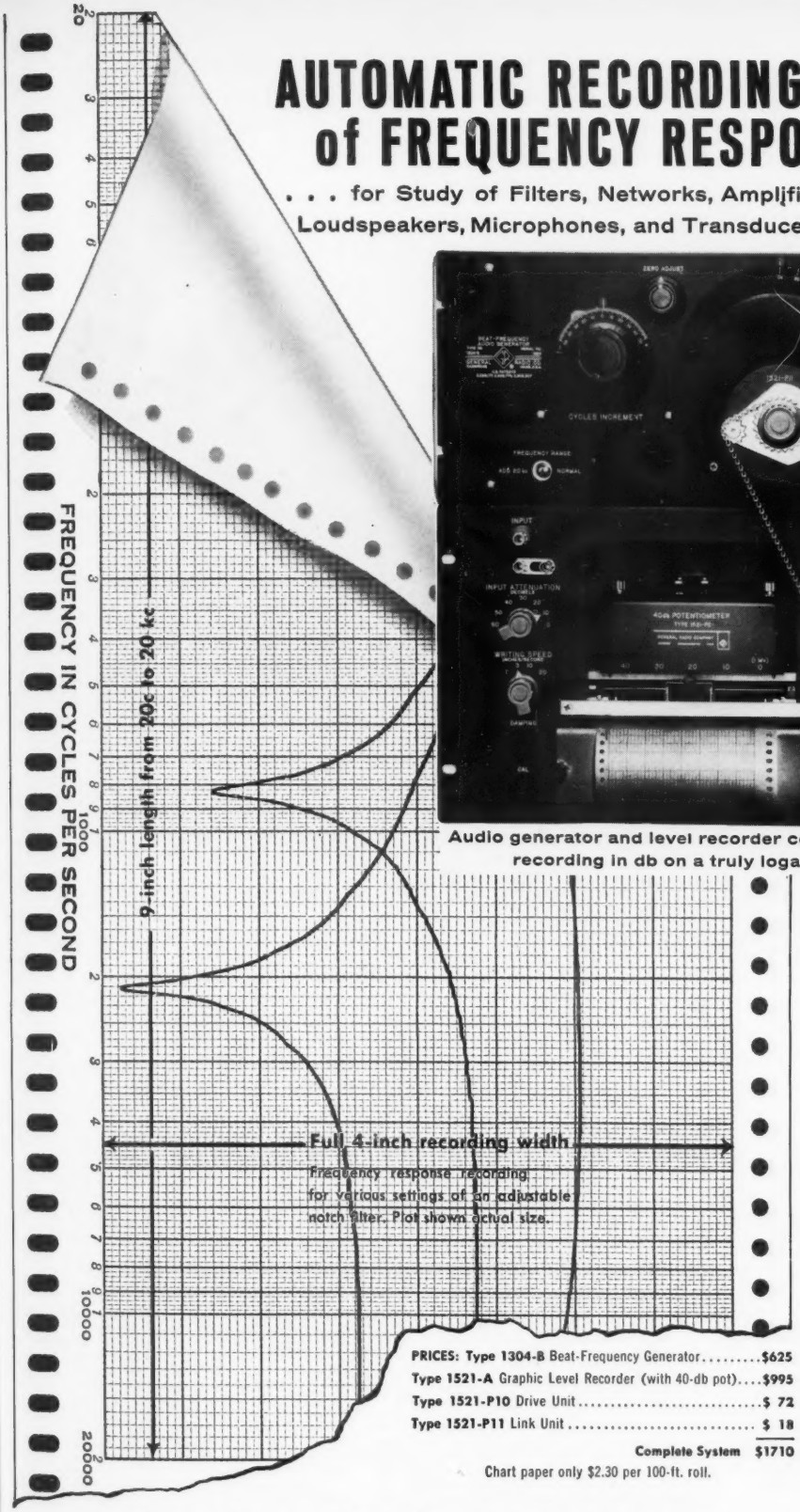
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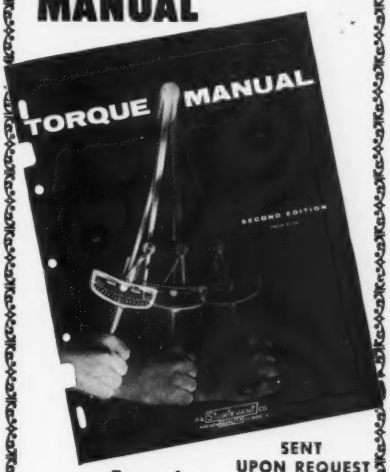

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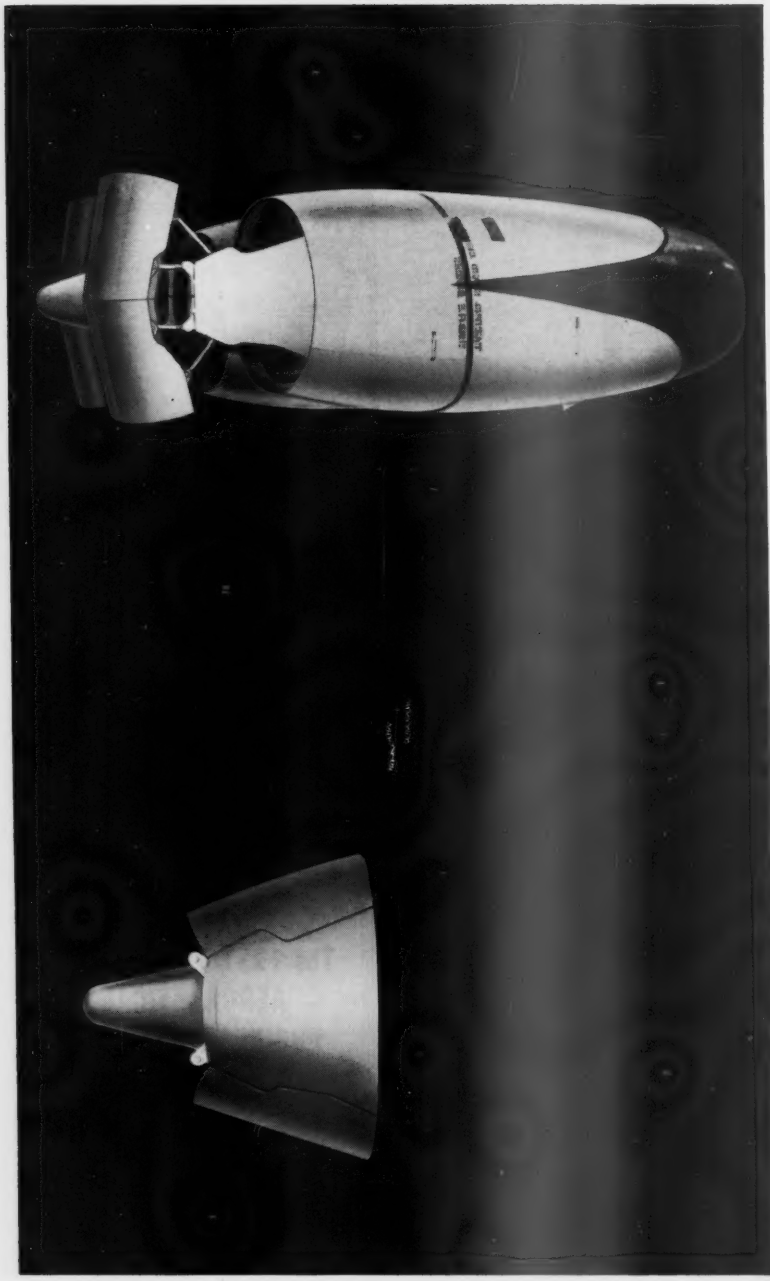

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ACOUSTICS, SOUND, NOISE

SIMILARITY OF FAR NOISE FIELDS OF JETS. Appendix A, B - SIMILARITY RELATIONS. Appendix C - EXPERIMENTAL DIFFERENCES AND ERRORS. W. L. Howes. US, NASA TR R-52, 1959. 90 pp. 27 refs. Derivation of similarity parameters for far-field noise from subsonic and supersonic jets issuing from circular nozzles. Relations for the total acoustic power, acoustic-power spectrum, acoustic directivity, local mean-square-pressure spectrum, and acoustic-pressure probability density are considered. Results show that subsonic data correlated well, as did supersonic data, with the exception of total-power similarity. Subsonic and supersonic correlations generally differed only slightly.

THE NEAR-SOUND FIELD OF TURBULENCE. Appendix A - EXPANDED FORM OF EQUATIONS FOR MEAN-SQUARE SOUND PRESSURE AND INTENSITY. Appendix B - VECTOR FORM OF EQUATIONS FOR MEAN-SQUARE SOUND PRESSURE AND INTENSITY. Appendix C - EFFECT OF CONVECTION OF TURBULENCE. G. J. Franz. US, Navy Dept., David Taylor Model Basin, Rep. 982, Oct., 1959. 34 pp. 24 refs. Derivation of general expressions for the velocity potential, particle velocity, instantaneous sound pressure, mean-square sound pressure, and sound intensity for the sound generated by turbulence, starting from Lighthill's fundamental relations for the density fluctuations in the medium outside a turbulent region. The frequency spectra and directional patterns of the sound observed at points in the sound field that are much less than a wavelength from a multipole sound sources are shown to differ significantly from the frequency spectra and directional patterns of the sound observed at points in the sound field that are many wavelengths from the multiple sound sources.

AN INVESTIGATION OF SOME ASPECTS OF THE SONIC BOOM BY MEANS OF WIND-TUNNEL MEASUREMENTS OF PRESSURES ABOUT SEVERAL BODIES AT A MACH NUMBER OF 2.01. H. W. Carlson. US, NASA TN D-161, Dec., 1959. 44 pp. Presentation of test results showing that, to the first order, the boom-producing pressure rise across the bow shock is dependent on the longitudinal development of body area and not on local details. Nonaxisymmetric shapes may be replaced by equivalent bodies of revolution to obtain satisfactory theoretical estimates of the far-field pressures.

AERODYNAMICS, FLUID MECHANICS

Aerothermochemistry, Dissociation, Ablation

AERODYNAMICALLY HEATED SURFACES - A CHEMICAL ANALYSIS. Howard Myers. Aero/Space Engrg., Feb., 1960, pp. 34-38, 103. 15 refs. Analysis of the chemical behavior of ablative missile surfaces, including both decomposition reactions and mass transfer. In many important cases the two processes can be analyzed independently; this is particularly true when the process of decomposition is clean-cut and well understood chemically, as it is in the case of plastics such as Teflon. The chemical properties of Teflon are used to illustrate the scheme of analysis. However, the method of analysis is not restricted to Teflon, but is applicable to any surface material for which the reaction kinetics of decomposition have been established.

THE HEAT PROTECTION POTENTIAL OF SEVERAL ABLATION MATERIALS FOR SATELLITE AND BALLISTIC RE-ENTRY INTO THE EARTH'S ATMOSPHERE. N. S. Diaconis, J. B. Fanucci, and G. W. Sutton. G-E MSVD AL TIS R59SD423, Sept. 11, 1959. 59 pp. 18 refs. USAF-supported analysis of the ablation and thermal penetration characteristics for three materials, each chosen as representative of a distinct category of ablators, performed for three specific trajectories. In particular, the materials chosen are Teflon, graphite, and quartz. It is demonstrated that on the basis of high heat flux environments (ICBM re-entry), low ablation rate characteristics reflected by heats of ablation dominate the choice of the material. Experimental values of ablation

for Teflon and transparent fused quartz agree reasonably well with theoretical calculations for this type of environment. Although large values of heats of ablation are indicated for graphite under these same conditions, its high backface temperatures prevent serious consideration as an ablating shield material. Only at extremely high heating rates does graphite show promise. At low heating rates of long duration, (satellite re-entry), heat penetration characteristics of the material dictate the choice. Experiments for such environments show values of heat of ablation for Teflon to be in agreement with theory. Comparison of these data with results for Teflon at the high heating rates appears to verify the trend of a pressure effect on the heat of ablation as predicted by Scala.

METHODS OF PREDICTING LAMINAR HEAT RATES ON HYPERSONIC VEHICLES. Appendix A - FRACTION OF ENERGY IN DISSOCIATION. Appendix B - FLOW PROPERTIES ON A YAWED CYLINDER. R. J. Wisniewski. US, NASA TN D-201, Dec., 1959. 36 pp. 14 refs. Summarized presentation of some theories on laminar heat transfer for flow in thermodynamic equilibrium. In some cases the effects of frozen flow are included. Emphasis is placed on the proper methods for obtaining heating rates to hypersonic bodies, wings, and control surfaces. The effects of yaw and the determination of the inviscid flow field are also considered.

NUMERICAL CALCULATION OF ABSOLUTE BREMSSTRAHLUNG INTENSITY FOR A FULLY IONIZED FULLY DISSOCIATED HYDROGENIC GAS. G. S. Janes and H. E. Koritz. Avco Everett Res. Lab. RR 70 (AFOSR TN 59-1076), Sept., 1959. 13 pp. Description of numerical calculations made on the IBM 650 using the approximate relationships established by Kirkpatrick and Weidmann. An expression was developed on the basis of the following assumptions: (a) the gas is fully ionized and dissociated and is composed of atomic hydrogen or deuterium; (b) the ions are assumed fixed with respect to the electrons; (c) the electron motion is completely random, so that as many electrons are moving in one direction as are moving in any other direction and, as a result, the angular dependence of the emitted photons is isotropic; and (d) at least electron thermodynamic equilibrium exists in the gas, thus permitting the utilization of the Maxwell-Boltzmann distribution function. A calibration method is also developed for measuring the absolute bremsstrahlung intensities, which continually compensates for the errors present in most calibration procedures.

TRANSPORT PROPERTY EQUATIONS FOR PARTIALLY IONIZED GASES. C. W. Baulknight. G-E MSVD AL TIS R59SD428, Oct. 18, 1959. 12 pp. 11 refs. USAF-supported theoretical investigation considering two types of systems: Type I is a system of charged-charged particles and the Coulomb interaction potential is assumed; in type II, the system is composed of both charged and uncharged particles - i.e., $N^+ + N$, and $\frac{1}{r^4}$ potential is assumed. Some typical results are presented for the diffusion, viscosity, and thermal conductivity coefficients for the charged-charged system in the temperature range of 10,000° to 15,000°K.

RECENT ADVANCES IN CHEMICAL KINETICS OF HOMOGENEOUS REACTION IN DISSOCIATED AIR. W. G. Zinman. G-E MSVD AL TIS R59SD426, Sept. 21, 1959. 19 pp. 41 refs. Survey of data showing that the kinetics of certain types of homogeneous gas phase reactions should be considered in many flow problems involving diatomic gases at moderate temperatures. The two general types of reactions are indicated -- atom recombination and two body reactions. In general, two body reactions are so rapid compared with atom recombination that certain equilibrium relations will be obeyed in many gas mixtures not in complete thermodynamic equilibrium. The rate constants necessary to determine when this can be done are given.

Aerothermodynamics

STUDY OF THERMAL DISCONTINUITIES AND ASSOCIATED TEMPERATURE DISTURBANCES IN A SOLID SUBJECT TO A SURFACE HEAT FLUX. III - EFFECT OF SENSORS IN LOW CONDUCTIVITY MATERIAL UPON TEMPERATURE DISTRIBUTION AND ITS MEASUREMENT. J. V. Beck. Avco Res. & Adv. Devel. Div. RAD TR 9 (7)-59-26, Oct. 12, 1959. 46 pp. USAF-supported analysis of the thermal effects of a high conductivity cylinder placed normal to a heated surface of a semi-infinite body. The thermal properties are assumed to be temperature dependent and the material is isotropic. It is shown that the temperature disturbances calculated for constant in time heat flux can be extended to time-variable heating conditions. The temperature disturbance at a sensor junction in an ablating body may also be determined, provided a protrusion is not caused at the ablating surface. The two main analyses given are: (a) an approximate analytical steady-state solution, including development of a technique for solving this problem and extension of the solution to cover the case of a composite thermocouple assembly which is inserted in a low-conductivity material; (b) analysis using the IBM 704 in solving the problem expressed as a set of finite difference equations.

HEAT-TRANSFER MEASUREMENTS AT A MACH NUMBER OF 2 IN THE TURBULENT BOUNDARY LAYER ON A FLAT PLATE HAVING A STEPWISE TEMPERATURE DISTRIBUTION. R. J. Conti. US, NASA TN D-159, Nov., 1959. 27 pp. 12 refs. Experimental investigation to determine the effects of a step in wall temperature upon the heat-transfer characteristics of a turbulent, compressible boundary layer along a flat plate. A transient heating technique is used for the measurements made under near-equilibrium conditions. The wall-temperature step caused sharp increases in heat-transfer coefficient downstream of the step, which were followed by a rapid decay. A maximum increase of 90% was measured and generally good agreement with a theory by Ferrari was found. The application of the theory is analyzed, and it is shown that for these test

conditions the heat-transfer coefficient given by Ferrari's theory is essentially the same as that predicted by means of incompressible flow theory.

EXPERIMENTAL INVESTIGATION OF METAL TEMPERATURES OF AIR-COOLED AIRFOIL LEADING EDGES AT SUBSONIC FLOW AND GAS TEMPERATURES UP TO 2780°F. F. S. Stepka and H. T. Richards. US, NASA TN D-127, Nov., 1959. 32 pp. 17 refs. Description of tests made on three configurations of internally cooled airfoil leading edges to determine their cooling characteristics and the effect of afterbody temperature on leading-edge temperature. A method for correlating the average leading-edge metal temperatures is presented. The experiments were conducted over a range of total gas temperatures from 1,660°F. to 2,780°F. and a range of afterbody reference temperatures from 600°F. to 1,675°F.

ANALYSIS OF TEMPERATURE DISTRIBUTION AND RADIANT HEAT TRANSFER ALONG A RECTANGULAR FIN OF CONSTANT THICKNESS. Seymour Lieblein. US, NASA TN D-196, Nov., 1959. 60 pp. Theoretical analysis of the one-dimensional steady-state radiant heat-transfer characteristics of rectangular fin plates of constant thickness with uniform heat source along the leading edge. Calculations of the variation of temperature and radiating effectiveness with distance from the heat source are made for infinite- and finite-length plates over a wide range of ratios of sink-to-source temperatures. Application of the solutions to a variety of environmental conditions is made possible through the determination of an equivalent sink temperature for the environment. Design parameters for minimizing plate volume are derived, and application of results to practical radiator considerations is indicated.

WALL TEMPERATURE AND HEAT TRANSFER OF A FLAT PLATE IN THE SLIP FLOW. Akira Takano. (Japan Soc. Aero. & Space Sci. Meeting, Oct. 20, 1958.) Japan Soc. Aero. & Space Sci. Trans., No. 2, 1959, pp. 11-21. Solution of an approximate equation, based on the boundary layer perturbation theory obtained previously, subject to the boundary conditions on the surface. The relation between the equilibrium wall temperature and the surface temperature of a gas is obtained and found to be a function of the free stream Mach Number and the ratio of wall temperature to that of the free stream. The character of the heat transfer in a rarefied gas is also studied on the basis of the kinetic theory for a non-Maxwellian gas and the present boundary layer approximation. In the general case, the heat flux to the surface is shown to result from the temperature jump at the surface, the slip flow along the surface, and the temperature gradient normal to the surface. In the boundary layer approximation, the coefficient of heat transfer and the Stanton Number are the same as those of the free molecular flow when the wall temperature is different from that at equilibrium.

ON MASS TRANSFER AND SHOCK-GENERATED VORTICITY. I - AXISYMMETRIC FLOW. II - CYLINDRICAL FLOW. H. Hoshizaki. Lockheed Aircraft Missiles & Space Div. TN LMSD-49721; LMSD-288075, May 22; Nov., 1959. 35; 29 pp. 20 refs. Analysis of the effects of shock-generated vorticity and mass transfer on stagnation-point heat transfer rates. The complete incompressible Navier-Stokes equations are considered in the flow region between the bow shock and the surface of spheres and cylinders. Numerical results are presented for a sphere, a cylinder, and a yawed infinite cylinder. The solutions are obtained for Reynolds Numbers between 500 and 10,000, four different values of the density ratio, and three values of the injection rate parameters. Results are presented in terms of the shock-layer velocity, temperature and vorticity profiles, shock-detachment distances, and Nusselt Numbers. It is concluded that the effect of shock-generated vorticity in increasing heat transfer rates over boundary-layer theory values is enhanced by mass injection into the shock-layer. The effectiveness of this mass injection in reducing aerodynamic heating is decreased by the vorticity generated by a curved shock wave. The effect of shock-generated vorticity on heat transfer is little affected by yaw.

AN EXPERIMENT ON THE INSULATING PROPERTIES OF BOUNDARY LAYERS. F. H. Durgin. MIT NSL TR 218 (AFOSR TN 57-392) [AD 132467], July, 1959. 140 pp. 54 refs. Theoretical and experimental investigation to determine which of several theories is best able to predict the insulating properties of the boundary layer. The model is a cone having the forward half cooled uniformly to about 100°F. below recovery temperature. The aft half is made of a good thermal insulator and is instrumented so that its temperature distribution could be measured. The cone is tested at a Mach Number of 3.5 and at Reynolds Numbers of 1.18×10^6 and 4.13×10^6 per ft. for the laminar and turbulent layers, respectively. Theoretical methods due to Baron, Lighthill, and Libby and Morduchow are used to predict the temperature decay over the aft part of the cone for the laminar case. Lighthill's theoretical results are in very close agreement with the experimental results. Methods due to Seban, Rubesin, and Hill are applied to the turbulent case. The experimental results fall about halfway between the predictions of Seban and Rubesin.

Boundary Layer

EFFECTS OF INTERACTION BETWEEN BOUNDARY LAYERS AND EXTERNAL STREAM AND OF INCIDENCE ON BOUNDARY-LAYER DRAG AT SUPERSONIC SPEEDS. A. D. Young and S. Kirkby. Gt. Brit., ARC CP 451, 1959. 67 pp. 15 refs. BIS, New York, $1.62. Determination of the boundary-layer drag of biconvex wing sections at supersonic speeds with zero heat transfer for a range of thickness-chord ratio up to 0.1, mainstream Mach Number up to 5.0, Reynolds Number, and transition position. Previous results

are extended and improved by allowing for the interaction of boundary layer and external stream, insofar as the resulting changes in the external pressure dristribution modify the skin friction distribution. Calculations are also made of the effect of incidence (up to 10°) on the boundary-layer drag of a flat plate. Included is an analysis of the effects on skin friction and boundary-layer pressure drag distribution of the main parameters investigated and, in particular, of the changes which accompany the increase in Mach Number. These changes are shown to be related to the changes in local free-stream Mach Number distribution and the associated changes in local free-stream density x velocity^2 ($\rho_4 u_4^2$). Tables presenting the detailed results are given along with figures summarizing the effects of thickness-chord ratio and incidence on boundary-layer drag.

TRANSITION IN A SEPARATED LAMINAR BOUNDARY LAYER. B. H. Lochtenberg. J. Aero/Space Sci., Feb., 1960, pp. 92-96. Investigation of transition in the flow past a step, with special reference to the boundary-layer flow above airfoil bubbles. Results show that transition in a separated laminar boundary layer is initiated by the formation of Tollmien-Schlichting waves. Instability develops more rapidly in a separated than in an attached boundary layer. The breakdown to turbulence in a separated layer is brought about by either a wave or a burst mechanism. The wave mechanism consists of the amplification, distortion, and breaking up of the Tollmien-Schlichting waves. The burst mechanism consists of the appearance and growth of spots of turbulence. Transition develops more rapidly with the burst than with the wave breakdown. Owen's criterion for long or short bubbles is shown to be insufficient to determine reattachment. It is suggested that a short bubble is the result of a burst type transition in the separated layer, and a long bubble is caused by the slower developing wave-type transition.

THE APPLICATION OF SUCTION TO A TWO-DIMENSIONAL LAMINAR SEPARATION BUBBLE. F. M. Burrows and B. G. Newman. Miss. State U. Aerophys. Dept. Res. Rep. 27, Oct. 1, 1959. 61 pp. 11 refs. Army-Navy-supported investigation of the effect of suction or blowing through a perforated surface in the vicinity of a laminar separation bubble. The bubble was produced at a sharp corner on one wall of a small wind tunnel and the tests were made at a low Mach Number under effectively two-dimensional conditions. It is found that the size of the bubble and the thickness of the boundary layer downstream are both reduced by increasing the suction and are similarly increased by much smaller amounts of blowing. Five different distributions of transpiration were tested and the various parameters describing the turbulent boundary layer downstream of reattachment are found to depend on the total quantity of flow removed and to be very nearly independent of the distribution itself. The measured values of pressure rise in the region of reattachment are roughly in agreement with a simple momentum analysis which includes the effect of transpiration. It is concluded that the application of suction near a short bubble on a high-lift wing will, in general, be beneficial unless the possible forward movement of the separation point leads to the formation of a long bubble.

APPROXIMATE CALCULATIONS OF THE LAMINAR BOUNDARY LAYER WITH SUCTION, WITH PARTICULAR REFERENCE TO THE SUCTION REQUIREMENTS FOR BOUNDARY-LAYER STABILITY ON AEROFOILS OF DIFFERENT THICKNESS/CHORD RATIOS. I, II. M. R. Head. Gt. Brit., ARC R&M 3124, 1959. 19 pp. BIS, New York, $1.26. Application of a previously developed method to problems where suction is applied through the surface. Solutions are given for the following cases: (a) flat plate with uniform suction and sinusoidal variation of external velocity, (b) flat plate with intermittent suction, (c) suction applied following the normal separation point to maintain a zero skin-friction layer for the flow U = 1-x, and (d) flat plate with uniform blowing. Results are given of comprehensive calculations for a series of airfoils with related pressure distributions. The distributions of suction required to maintain neutral stability of the boundary layer are given as functions of thickness/chord ratio and Reynolds Number. The effect of Mach Number is also inferred on certain simplifying assumptions.

THE INFLUENCE OF THE GROUND ON THE AERODYNAMIC PROPERTIES OF AN AIRFOIL WITH JET FLAP. W. J. Prosnak and P. Kucharczyk. Arch. Mech. Stosowanej, No. 4, 1959, pp. 475-509. 12 refs. Analysis considering the problem of whether the jet flap in the proximity to the ground preserves its ability to increase lift over the airfoil. The image profile is used to construct the complex potential corresponding to the flow past the two jet-flap profiles. The aerodynamic coefficients are then calculated for one profile of the pair. The results show that if the ratio $\delta = l/h$ (l being the chord and h the distance from the ground) is two, the lift of a profile without jet flap increases by about 15% to 30%, and the efficiency of the jet flap by about 8% to 50%, smaller values corresponding to greater angles of incidence ($\alpha = 10°$) and greater ones to smaller angles of incidence ($\alpha = 2°$).

AN APPROXIMATE METHOD OF CALCULATING THE LAMINAR BOUNDARY LAYER IN TWO-DIMENSIONAL INCOMPRESSIBLE FLOW. M. R. Head. Gt. Brit., ARC R&M 3123, 1959. 53 pp. 27 refs. BIS, New York, $3.60. Development of an approximate method using a doubly-infinite family of boundary-layer velocity profiles which enables the momentum and energy integral equations of the boundary layer to be satisfied exactly, together with the first compatibility condition of the surface. The principal characteristics of the velocity profiles used have been calculated and are presented graphically in a series of charts which enable calculations to be carried out with a minimum of labor. No important restrictions on the application of the method have appeared; in particular, it has been found possible to deal with certain types of flow giving rise to similar profiles and

with distributed suction starting either at the leading edge or at some point downstream.

Control Surfaces

LIFT AND DRAG CHARACTERISTICS AT SUBSONIC SPEEDS AND AT A MACH NUMBER OF 1.9 OF A LIFTING CIRCULAR CYLINDER WITH A FINENESS RATIO OF 10. V. E. Lockwood and L. W. McKinney. US, NASA TN D-170, Dec., 1959. 21 pp. Description of a wind-tunnel investigation made to determine the feasibility of using small flaps to develop lift for possible re-entry application. Several full-span flaps attached normal to the lower surface of the cylinder and varying in chord from 0.004- to 0.300-diam. were used as lift-generating devices. Most of the tests were made with the flaps at the 50%-chord station, but in others the chordwise location was one of the variables. Results indicate that lift could be generated throughout the range of Mach Numbers investigated; for flaps located at the 50%-chord station, increases of flap size up to 20% of the cylinder diameter give increases of lift coefficient, a maximum of 1.63 being obtained at a Mach Number of 0.3; the lift effectiveness of all flaps decreases rapidly above a Mach Number of about 0.3, but is positive for all Mach Numbers of the investigation when the flap chord is 5% or greater; the drag of a lifting circular cylinder increases rapidly at subcritical Mach Numbers as the flap chord is increased, but at a Mach Number of 1.9 the drag of the cylinder with the 10%-chord flap is only about 7% higher than that of the nonlifting cylinder.

Flow of Fluids

NON-EQUILIBRIUM FLOW OVER A WAVY WALL. W. G. Vincenti. J. Fluid Mech., Nov., 1959, pp. 481-496. 11 refs. Presentation of a small-disturbance solution for the steady two-dimensional flow over a sinusoidal wall of an inviscid gas in vibrational or chemical nonequilibrium. The results are based on a single, linear, third-order partial differential equation. The solution is valid throughout the range from subsonic to supersonic speeds and for all values of the rate parameter from equilibrium to frozen flow. The results illustrate some of the properties of nonequilibrium flow, such as the occurrence of pressure drag at subsonic speed and the absence of the discontinuous phenomena that characterize the Prandtl-Glauert theory when the flow changes from subsonic to supersonic.

ON THE STABILITY OF A SHEAR LAYER. J. Menkes. J. Fluid Mech., Nov., 1959, pp. 518-522. Analysis on the effects of density variation in the absence of gravity on the stability of a horizontal shear layer between two streams of uniform velocities. The density is assumed to decrease exponentially with height and the velocity is represented by $U(y) = \tanh y$. The method of small disturbances is used to obtain the neutral stability curve. It is demonstrated that disturbances with wave numbers larger than the width of the transition layer are attenuated. Qualitative agreement with experimental evidence is obtained.

WORKING CHARTS FOR RAPID PREDICTION OF FORCE AND PRESSURE COEFFICIENTS ON ARBITRARY BODIES OF REVOLUTION BY USE OF NEWTONIAN CONCEPTS. R. W. Rainey. US, NASA TN D-176, Dec., 1959. 36 pp. Presentation of a simplified method for obtaining loading, or pressure, distributions and aerodynamic characteristics of arbitrary bodies of revolution. The equations are presented in such a form as to facilitate an investigation of the effects of Mach number variation and changes in specific heat ratio upon the aerodynamic characteristics.

PRESSURE AND FORCE CHARACTERISTICS OF NONCIRCULAR CYLINDERS AS AFFECTED BY REYNOLDS NUMBER WITH A METHOD INCLUDED FOR DETERMINING THE POTENTIAL FLOW ABOUT ARBITRARY SHAPES. E. C. Polhamus, E. W. Geller, and K. J. Grunwald. US, NASA TR R-46, 1959. 78 pp. 13 refs. Description of theoretical studies and low-speed wind-tunnel measurements, including the effect of Reynolds Number and the flow incidence for various elliptical and basically square and triangular cross sections investigated in the Reynolds Number range from approximately 0.3×10^6 to 1.5×10^6. All cross sections exhibited rather large Reynolds Number effects, particularly with regard to side force. The type of flow associated with the large variations in side force was determined for two of the cross sections by comparing the experimental and theoretical pressure distributions. Application of the data in predicting the spin characteristics of fuselages is briefly discussed.

MEASUREMENTS OF PRESSURE AND LOCAL HEAT TRANSFER ON A 20° CONE AT ANGLES OF ATTACK UP TO 20° FOR A MACH NUMBER OF 4.95. J. D. Julius. US, NASA TN D-179, Dec., 1959. 28 pp. 13 refs. Presentation of data on the distribution of pressure and local heat transfer on an included-angle cone obtained in a Reynolds number range of 14×10^6 to 75×10^6 per foot, based on free-stream conditions. The measured pressures are compared with the first-order and second-order approximations of exact cone theory and with Newtonian and modified Newtonian theory. The heat-transfer rates along the most windward generator of the cone increased with increasing angle of attack; heat transfer was greatest along the most windward generator, $\phi = 0°$, when the flow was wholly laminar. When transition was observed, the $\phi = 30°$ generator generally showed the highest heat transfer.

INVESTIGATION OF THE FLOW OVER A SPIKED-NOSE HEMISPHERE-CYLINDER AT A MACH NUMBER OF 6.8. D. H. Crawford. US, NASA TN D-118, Dec., 1959. 59 pp. 30 refs. Study of the shape and nature of the flow over a spiked-nose hemisphere-cylinder for a Reynolds number range of 0.12×10^6 to 1.5×10^6. Schlieren photographs show the effect of varying the spike length and Reynolds number upon the shape of the separated boundary and upon the location of transition. The heat transfer and pressure distribution over the body are correlated with the location of

the start of separation, the location of reattachment, and the location of the start of transition.

OBTEKANIE KONUSA VIAZKIM TEPLOPROVODNYM GAZOM S BOL'SHIMI SVERKHZVUKOVYMI SKOROSTIAMI. V. V. Lunev. Prikl. Mat. i Mekh., Nov.-Dec., 1959, pp. 1006-1018. 12 refs. In Russian. Study of the flow of viscous, heat-conducting gas around a cone with zero angle of attack at high supersonic velocities. The region of turbulent flow is divided into two separated subregions: (a) viscous, in which the flow is assumed to be laminar and described by boundary-layer equations; (b) nonviscous, in which the flow is represented by the equations of ideal gas. Only the case of interaction is considered - i.e., the flow region sufficiently removed from the cone nose. The basic solution is that of the equation of the infinitely thin boundary layer over the cone, reduced to the problem of plates, and the tabulated conical flow of ideal gas. The surface of the cone is assumed to be isothermal and heat insulated.

HYPERSONIC SHOCK-LAYER THEORY OF A YAWED CONE AND OTHER THREE-DIMENSIONAL POINTED BODIES. H. K. Cheng. Cornell Aero. Lab. Rep. (USAF WADC TN 59-335), Oct., 1959. 60 pp. 33 refs. Application of the shock-layer approximation in conjunction with small perturbations in the yaw angle to the problem of hypersonic flow over yawed circular cones. The basic problem of nonuniform validity related to the small-perturbation procedure is examined, and a uniformly valid first-order solution is obtained, providing an explicit description of the shock-layer structure and exhibiting a vortical sublayer near the base of the shock layer. Analytic formulas for pressure and circumferential velocity are given to the second-order approximation which includes the nonlinear yaw effect. A study of three-dimensional hypersonic flows is also made within the framework of the shock-layer theory, covering the properties of the flow field within the shock layer; certain behavior of the flow field in the immediate vicinity of a pointed, but otherwise arbitrary, body; the streamline pattern on the surface; the vertical sublayer near the inner edge of the shock layer; and the enthalpy and flow speed.

EQUATIONS AND CHARTS FOR DETERMINING THE HYPERSONIC STABILITY DERIVATIVES OF COMBINATIONS OF CONE FRUSTUMS COMPUTED BY NEWTONIAN IMPACT THEORY. L. R. Fisher. US, NASA TN D-149, Nov., 1959. 33 pp. Presentation of equations and charts from which the Newtonian impact theory values of the stability derivatives of cone frustums may be determined for small angles of attack. A procedure is also developed for estimating by means of the impact theory the coefficients for a missile shape which is made up of more than one cone frustum or a spherical nose together with one or more cone frustums.

SUPERSONIC FLOW PAST A FAMILY OF BLUNT AXISYMMETRIC BODIES. M. D. Van Dyke and H. D. Gordon. US, NASA TR R-1, 1959. 25 pp. 14 refs. Supt. of Doc., Wash., $0.35. Description of a number of numerical computations carried out for unyawed bodies of revolution with detached bow waves. The gas is assumed perfect with $\gamma = 5/3$, 7/5, or 1. Free-stream Mach numbers are taken as 1.2, 1.5, 2, 3, 4, 6, 10, and ∞. The results are presented in summarized form, with emphasis on those obtained for the sphere and the paraboloid.

EXPERIMENTS WITH INCLINED BLUNT-NOSED BODIES AT $M_0 = 2.45$. I. M. Hall, E. W. E. Rogers, and B. M. Davis. Gt. Brit., ARC R&M 3128, 1959. 28 pp. 22 refs. BIS, New York, $1.80. Investigation of flows about flat-nosed and hemispherical-nosed bodies of revolution at incidences up to 28°. Schlieren photographs were taken in the plane of symmetry, and the vortex wake was studied by the vapor-screen technique. The vortex wake tended to remain stable to higher incidences than had been found for pointed-nosed bodies. Instability was first observed at incidences of 15°, and was more pronounced in the wake of the flat-nosed body. Surface-pressure measurements were made, and the results integrated to give the axial forces and the distribution of normal forces on the bodies.

SLENDER-BODY THEORY BASED ON APPROXIMATE SOLUTION OF THE TRANSONIC FLOW EQUATION. J. R. Spreiter and A. Y. Alksne. US, NASA TR R-2, 1959. 54 pp. 43 refs. Supt. of Doc., Wash., $0.55. Derivation of approximate solutions for the pressure distribution on pointed slender bodies of revolution for flows with a free-stream Mach number of 1, and for flows that are either purely subsonic or purely supersonic. A method based on local linearization, introduced recently in the analysis of similar problems in two-dimensional flow, is used in the calculation. The theory is developed for bodies of arbitrary shape, and specific results are given for cone-cylinders and for parabolic-arc bodies at zero angle of attack. Also included is a comparison of the derived results with existing theoretical and experimental data.

THE FLOW PAST A CLOSED BODY IN A HIGH SUBSONIC STREAM. J. B. Helliwell. Quart. J. Mech. & Appl. Math., Aug., 1959, pp. 298-313. USAF-sponsored solution of Tricomi's equation for the flow past a thin, doubly symmetric body placed at zero incidence in a high subsonic stream in which sonic velocity is attained along a segment of the body. This flow is the compressible analog of the Riabouchinsky model for incompressible fluids. The singularity in the hodograph plane, corresponding to the point at infinity in the physical plane, is essentially different from that which occurs in other similar problems. The boundary value problem is of a mixed type, and this is shown to lead to a pair of dual integral equations for which the solution is obtained. Numerical results are given which specify the dimensions of the body corresponding to a range of incident Mach Numbers.

A REVIEW OF THE LITERATURE OF PLASMA PHYSICS. E. E. Covert and Keith Kerney. MIT

NSL TR 373 (USAF WADC TR 59-486), July, 1959. 176 pp. 670 refs. Discussion of the level of development of plasma physics. It is found that the present theories account for the experimental effects if (1) the plasma is sufficiently dense that the time between collisions is small compared to the time an atom stays in the excited state, but is sufficiently rare that the volume of the particles making up the plasma is very much smaller than the volume of plasma; (2) the potential energy between particles is the sum of the particles' potential energy; and (3) the excitations are sufficiently weak, or the duration of the event is sufficiently short, that linearized theories are applicable.

PLASMA DYNAMICS. F. H. Clauser. Johns Hopkins U. Dept. Aero. Rep. (AFOSR TR 59-125), Aug., 1959. 75 pp. Study of one-dimensional, steady flow of a gas consisting of particles all having the same sign of their electrical charge. The question of what dynamic equations govern such flow is discussed. The full range of behavior from zero Mach Number to infinite Mach Number is explored as is the full range of the effect of external electric fields on the flow. It is found that the nonlinearity of the equations introduces several fundamental new concepts to fluid mechanics. It is also found that under some conditions a number of radically different flows can exist for exactly the same set of boundary conditions. Under other conditions, no flows whatever exist that fit the boundary conditions.

PLASMA ACCELERATION BY USE OF GUIDED MICROWAVES. R. V. Hess and Karlheinz Thom. US, NASA TN D-46, Dec., 1959. 46 pp. 16 refs. Evaluation of a method of plasma acceleration using the radiation pressure of microwaves intensified in a resonant cavity as the driving pressure. When used to accelerate the plasma, the radiation can be compared to a gas which, however, is almost free of inertia and can expand with a velocity approaching the velocity of light.

ON A LAMINAR FREE-CONVECTION FLOW AND HEAT TRANSFER OF ELECTRICALLY CONDUCTING FLUID ON A VERTICAL FLAT PLATE IN THE PRESENCE OF A TRANSVERSE MAGNETIC FIELD. Yasuo Mori. Japan Soc. Aero. & Space Sci. Trans., No. 2, 1959, pp. 22-26. Study of the effect of a magnetic field on velocity profile, temperature profile, and heat transfer rate. The boundary layer equations for self-preserving flows are integrated numerically for the Prandtl Number of unity. A similarity solution exists if the magnetic field intensity varies according to $\pm 1/4$ power of the distance from the leading edge of the plate. The nondimensional quantity given by the product of the magnetic parameter and the distance from the leading edge expresses the effectiveness of the magnetic field. It is found that the velocity profile is flattened and the heat transfer rate is reduced by the magnetic field.

GIPERZVUKOVOE OBTEKANIE TEL V MAGNITNOI GIDRODINAMIKE. M. D. Ladyzhenskii. Prikl. Mat. i Mekh., Nov.-Dec., 1959, pp. 993-1005. In Russian. Study of the hypersonic flow around bodies with an internally generated magnetic field in order to determine the influence of the strong applied magnetic field on the overall flow characteristics. The flow around wedges and cones is considered in detail for the case when the magnetic field intensity vector is directed normal to the surface of the body. The method of solution is based on the assumption of a narrow turbulent zone between the body and the shock wave. The forces acting upon the body are determined, and it is found that, in the case of sufficiently strong fields, the magnetic resistance has the same order of magnitude as the gasdynamic force, regardless of the narrowness of the turbulent zone affected by the magnetic field. It is shown that, under certain conditions, flow separation can occur, and the location of the point on the surface of the body over which magnetic separation occurs is determined. With increasing field intensity this point is displaced upstream and, by using strong fields, it becomes possible to generate regions of separation in the vicinity of bodies, thus leading to an increased drag and, hence, decreased heat transfer to the body.

A STUDY OF THE STRUCTURE OF THE MAGNETOHYDRODYNAMIC SWITCH-ON SHOCK IN STEADY PLANE MOTION. Z. O. Bleviss. Douglas Rep. SM-23720, Oct., 1959. 33 pp. 10 refs. Analysis of the steady magnetohydrodynamic switch-on shock wave for several order-of-magnitude orderings of the four diffusivities involved in the problem. The various orderings are approximated by allowing one or more of the appropriate diffusivities to approach zero, and approximate solutions that are uniformly valid to order unity are sought. In general, singular perturbation problems are encountered, the number of them (from zero to a maximum of three) depending upon the ordering of the diffusivities and the magnitude of the downstream velocity normal to the shock relative to certain critical velocities downstream of the shock. For most of the cases considered, the limiting forms of the integral curves are determined and are sketched in appropriate three-dimensional phase spaces.

ZADACHA O PORSHNE V MAGNITNOI GIDRODINAMIKE. G. Ia. Liubarskii and R. V. Polovin. AN SSSR Dokl., Oct. 1, 1959, pp. 684-687. 13 refs. In Russian. Qualitative analysis of the general piston problem in magnetohydrodynamics covering the case of constant speed. The infinite half-space $x > 0$ is filled with an ideally conducting liquid located in a magnetic field and at rest at the time $t = 0$. The state of the liquid is characterized by the density ρ_0, pressure p_0, and components of the magnetic field H_x, H_{0y}, $H_{0z} = 0$. The presence of two types of magneto-acoustic waves separated by constant flow regions is shown. The formula defining discontinuities in wave density is also given.

SOME FURTHER RESULTS ON HEATING A SUPERSONIC GAS STREAM WITH A RADIO FREQUENCY DISCHARGE. F. O. Smetana. USCEC

Rep. 56-207 (AFOSR TN 59-1127), Nov. 1, 1959. 16 pp. Investigation of r-f discharge heating of a supersonic gas stream. Temperature increases of at least 600°F. were recorded, although the pressure of strong electrical fields made it extremely difficult to interpret temperature indications. The action of the ionized gas and the strong field limits the type of material which may be used for nozzle materials. Qualitative indications of the decay of active species, N-N recombination, wall heating, effect of pressure, nozzle configuration, and electrode configuration were also obtained.

CONTINUUM EQUATIONS IN THE DYNAMICS OF RAREFIED GASES. Max Krook. J. Fluid Mech., Nov., 1959, pp. 523-541. Presentation of a procedure for translating boundary-value problems of gas dynamics from microscopic form into approximately equivalent continuum form. The continuum formulations involve state-variables that are either half-space moments or complete moments of the molecular distribution functions. Moment equations derived from the kinetic equations are reduced to a determinate set by representing the distribution functions as sums of "modified Maxwellian functions based on various characteristic temperatures and velocities." The particular choice of such a representation depends on the Knudsen number and on the nature of the microscopic boundary conditions.

Internal Flow

ON THE DEVIATION OF OUTLET FLOW ANGLES CAUSED BY SECONDARY FLOWS IN TURBINE CASCADES. I. Marusuke Gomi. JSME Bul., Nov., 1959, pp. 608-615. Development of a simple formula for calculating the mean outlet flow angle, assuming the secondary vortices concentrated at the blade centroid. The actual circulations around the blades are computed using Smith's equation. It is shown that the deviation of outlet flow angle increases with the inlet flow angle and with the spacing of the cascade, especially in an impulse cascade of large camber angle.

ON RAO'S METHOD FOR THE COMPUTATION OF EXHAUST NOZZLES. Gottfried Guderley. ZFW, Dec., 1959, pp. 345-350. Study of the physical ideas underlying Rao's work for determining nozzle forms that give maximum thrust at a limited length, and extension of his method to axisymmetric flows with nonconstant entropy. The main idea is the introduction of a suitable control surface to determine the momentum and other quantities, the form of the control surface and the velocity distribution along it being unknown.

THE BEHAVIOUR OF AN AXIALLY SYMMETRIC SONIC JET NEAR TO THE SONIC PLANE. M. G. Smith. Quart. J. Mech. & Appl. Math., Aug., 1959, pp. 287-297. Study of the behavior near the sonic plane of an axially symmetric sonic jet of gas emerging into a region of lower pressure. The form of the singularity at the sonic plane is found, and the lowest terms of the series expansions of the variables of state near to the plane are obtained. In particular, the corresponding solutions for this case and for the two-dimensional problem are compared, and it is shown that there are important differences between them.

Performance

THE ESTIMATION OF SHORT-TIME FLIGHT PATHS FOR INTERCEPTION DASHES. Ray Holland, Jr. USAF MDC TN 59-33, Nov., 1959. 27 pp. Presentation of a method to systematize the selection of a short-time flight path. It is intended to be used as the first approximation in an iterative variational computation for determining a true minimum time path for interception dashes. The method applies to an aircraft already airborne flying in a short time from specified initial values of horizontal position x_o, altitude y_o, and velocity v_o to specified destination values of horizontal position x_n and altitude y_n, remaining at all times in a single vertical plane.

Stability & Control

THE INTERPRETATION OF NONLINEAR PITCHING MOMENTS IN RELATION TO THE PITCH-UP PROBLEM. G. S. Campbell and Joseph Weil. US, NASA TN D-193, Dec., 1959. 32 pp. 11 refs. Presentation of practical methods for predicting the longitudinal response of an aircraft to arbitrary control inputs using nonlinear aerodynamic data. These methods are used to study some of the factors affecting pitch-up motions encountered by aircraft having regions of reduced stability: pitching-moment shape, control movement, dynamic pressure, aircraft moment of inertia, and aerodynamic damping. The effectiveness of automatic stabilization devices in reducing pitch-up severity is also considered.

Wings & Airfoils

THE SECOND ORDER THEORY OF THE SUPERSONIC THREE-DIMENSIONAL THIN-WING-EXPANSION. Michiya Sugo. (Natl. Congr. Theoret. & Appl. Mech. 7th Annual Meeting, 1957.) Japan Soc. Aero. & Space Sci. Trans., No. 2, 1959, pp. 1-10. 13 refs. Application of the PLK techniques to the particular solution of the second-order equation in the form of a combination of linear potentials, which are analogous to Van Dyke's consideration. However, it is a slightly restricted solution that satisfies the equation of the second order in the neighborhood of the wing surface and asymptotically approaches the second-order solution of the axially symmetric equation far from the surfaces found by Van Dyke. For subsonic and supersonic leading edges of delta wings, the pressure distributions are calculated, and the lift curve shape is also given for the latter case.

TRIM DRAG AT SUPERSONIC SPEEDS OF VARIOUS DELTA-PLANFORM CONFIGURATIONS M. E. Graham and B. M. Ryan. Douglas Rep. SM-23635, July, 1959. 96 pp. Application of the linear theory to study the drag due to lift and the

maximum lift/drag ratio at supersonic speeds of zero-thickness, trimmed, statically stable (a) delta-wing-plus-tail, (b) delta-wing-plus-canard, and (c) delta-wing-alone configurations. These configurations do not include a body. In general it is found that the drag due to lift decreases and the maximum lift/drag ratio increases with increasing aspect ratio, vertical gap, and "tail length;" and decreasing static margin; also, suitable camber and twist decrease the drag. However, calculations for wing-flap configurations indicate that if full leading-edge thrust exists, there is a range of aspect ratio in which decreasing the aspect ratio decreases the drag due to lift. If the leading-edge thrust exists, or if the surfaces are twisted and cambered, there can sometimes be less drag at a small positive static margin that at zero static margin. It is found that the choice of a type of trim surface (tail, canard, or flap) will depend primarily upon considerations other than supersonic cruise performance. The major influence upon the cruise lift-drag ratio will then be these other considerations rather than the direct optimization of the configuration to give the highest $(L/D)_{max}$ for the supersonic condition.

AEROELASTICITY

A STUDY OF VELOCITY-FREQUENCY-DAMPING RELATIONSHIPS FOR WING AND PANEL BINARY SYSTEMS IN HIGH SUPERSONIC FLOW. M. B. Zisfein and F. J. Frueh. Bell Aircraft Rep. 9015-19-001 (AFOSR TN 59-969), Oct., 1959. 55 pp. 11 refs. Application of piston theory aerodynamics to study two kinds of binary systems – pitch-plunge wings and two degree-of-freedom, simply supported panels. A major portion of the effort is focused on the effects of viscous and structural damping on the flutter and dynamic response characteristics and the relations between them. The characteristic equations of the binary systems are derived from Lagrangean mechanics and are solved for the velocity-frequency-damping relationships of these systems. From these closed-form solutions, by means of gross simplifications, several new concepts (base curve and high damping and decay asymptotes) are postulated. Also from the closed-form solutions, new simple relations between flutter damping and dynamic response are derived. These relations are then used to explain the hitherto unexplained phenomenon of "loopbacks" in the curves of velocity versus required damping.

FLIGHT DYNAMICS OF LARGE EXTERNAL STORES. A. P. Schaffer. Aero/Space Engrg., Feb., 1960, pp. 39-44. Discussion of flight flutter investigation experiences on the Grumman F11F-1 aircraft as a guide to the preliminary design and flight testing of relatively large external stores. The program was performed with instrumented test vehicles in a variety of aircraft and store configurations. Results are summarized and show the dependence of wing and store stability on inertial, structural, and aerodynamic variations.

AIRPLANES

Landing, Landing Loads

AN ANALOG STUDY OF AN AIRBORNE AUTOMATIC LANDING-APPROACH SYSTEM. J. J. Adams. US, NASA TN D-105, Dec., 1959. 57 pp. Study of an automatic approach control system which uses error information obtained with a simple radar target located at the end of the runway and a radar tracking set and attitude-measuring equipment carried in the aircraft. A swept-wing jet fighter aircraft was represented by six-degree-of-freedom equations with linear aerodynamic coefficients. The radar and attitude information was assumed to be free of any lag or dynamics, and most of the nonlinearities introduced by radar and gyro gimbal effects were included. The effects of various initial conditions and disturbances, such as flap deflection, gust disturbances, and radar noise were investigated. An analog computer was used to carry out the investigation.

CONTROL THEORY

A STATISTICALLY AVERAGED CRITERION FOR FEEDBACK-SYSTEM SYNTHESIS. John Zaborsky and J. W. Diesel. J. Aero/Space Sci., Feb., 1960, pp. 128-134, 160. 34 refs. Development of a performance criterion for feedback control systems, based on the averaging of penalized error values over such times when output is actually utilized. This is accomplished by assigning a probability to the time of output utilization. The criterion is a suitable starting point of design since it unifies in one summary the various specifications normally used to describe special aspects of performance.

FUELS & LUBRICANTS

RESEARCH ON ULTRA-ENERGY FUELS FOR ROCKET PROPULSION. Appendix A - 4.2°K IRRADIATION STUDIES, H. E. Weaver, R. C. Rempel, and L. H. Piette. Appendix B - FREE RADICALS IN SOLID-PROPELLANT SYSTEMS. J. M. Flournoy, L. H. Baum, Seymour Siegel, Ahlborn Wheeler, George Moe, E. I. Hormats, W. H. Andersen, and Sol Skolnik. Aerojet-Gen. Rep. 1690 (AFOSR TR 59-169), Oct., 1959. 140 pp. 69 refs. Summary of the results of research on the stabilization of energetic free radicals. Hydrogen atoms, hydroxyl radicals, and other normally unstable chemical species produced by ionizing radiation and by electric discharges are stabilized at low temperatures. The rate of disappearance of some of these radicals is studied over a range of temperatures, using electron-paramagnetic-resonance techniques. The heat released by the recombination of hydroxyl radicals in ice near 100°K. has been measured. The adsorption of hydrogen atoms on glassy materials at normal temperatures has been investigated and found to involve a variety of different adsorption rates. The general problems involved in the production, storage, and utilization of high concentration of free radicals are briefly summarized.

INVESTIGATION OF LIQUID NITRIC OXIDE AS A ROCKET OXIDIZER. L. E. Bollinger and Rudolph Edse. USAF WADC TR 59-12 [AD 208327], May, 1959. 22 pp. Experimental investigation of the use of liquid nitric oxide as oxidizer for rocket engines. It is found that extremely long residence times are required for the propellant in the combustion chamber. Methyl alcohol was used as the fuel and most of the experiments were conducted with a nominal 50-lbs. thrust motor having a characteristic length of 1,515 in.; the design chamber pressure was 300 psi. Results show that nitric oxide may affect the smooth combustion of nitric acid with a fuel due to the long chemical reaction time of nitric oxide.

MISSILE, ROCKET, & SPACE TECHNOLOGY

MANNED NUCLEAR SPACE SYSTEMS. I - HIGH-THRUST NUCLEAR SYSTEMS. II - LOW-THRUST NUCLEAR SYSTEMS. E. B. Konecci, R. F. Trapp, and M. W. Hunter. Aero/Space Engrg., Jan.; Feb., 1960, pp. 34-41; 49-54. 19 refs. Studies of a proposed mission to Mars for two different power systems considering radio-biological, life-support, and radiation shielding problems. A possible major disadvantage of the ion or (low-thrust) vehicle is that the whole massive system must be boosted, assembled, and checked out in orbit. It appears that high-thrust systems are quite applicable to short mission time, whereas the low-thrust systems lean toward longer trip times and large payloads. Shielding does not have a serious effect on either system even though low-thrust systems require larger total energies.

GRAPHICAL TRAJECTORY ANALYSIS. A. S. Boksenbom. US, NASA TN D-64, Dec., 1959. 46 pp. Presentation of a simple graphical method for two-body trajectory problems. The basic graph used is composed simply of circles and straight lines; all features of trajectories appear on the map; coasting trajectories correspond to circles on the graph. The transfer to new orbits on impulsive thrust, planar and nonplanar, is constructed on the same map. Approximations for continuous thrust and for cases of almost circular orbits are shown. Examples are given for cases of transfer to new orbits, optimization on the velocity increment ΔV, interplanetary trips, and some rendezvous problems.

OPTIMUM TRAJECTORY PROBLEMS: SOME SPECIAL CASES. E. W. Graham and B. J. Beane. Douglas Rep. SM-23687, Sept. 16, 1959. 51 pp. Study of the transfer of a rocket vehicle from one point to another with minimum fuel expenditure. The velocity vectors at the terminal points and the time for transfer are specified, and it is assumed that the vehicle is operated in a gravitational field without atmospheric resistance. In the examples studied two physical factors of particular importance are (a) the angle between the terminal velocity vectors in the moving system and (b) the angular orientation of these vectors in the perturbation force field. Two types of analysis are considered. The first is restricted to short transfer times, but applies to arbitrary gravitational fields. The second is restricted to transfer between points on a radial line in a central force field, but the time for transfer can be large if the terminal points are properly spaced. In both methods the restrictions offer material simplifications, but each method covers some problems in which intermediate impulses are desirable and some in which terminal impulses alone are optimum. Specific examples are included as illustrations.

FREE FLIGHT OF A BALLISTIC MISSILE. A. D. Wheelon. ARS J., Dec., 1959, pp. 915-926. 21 refs. Study of the free flight portion of a missile trajectory in analytic form. A simplified analysis using a spherical, nonrotating earth model is discussed first, and the corresponding error coefficients are determined for the missile burnout variables. Necessary corrections for the earth's rotation and oblateness are then introduced. Finally, consideration is given to the effect of gravitation anomalies and uncertainties in the fundamental geophysical constants which are found to be very small.

OPTIMAL ACCURACY ROCKET TRAJECTORIES. Appendix I - NUMERICAL SOLUTION IN KEPLER FIELD. Appendix II - METHOD FOR PARAMETER ADJUSTMENT. G. A. Baker, Jr., K. W. Ford, and Ch. E. Porter. J. Appl. Phys., Dec., 1959, pp. 1925-1932. Application of a slightly modified version of the rocket optimization formulation of Fried to facilitate the study of maximum accuracy trajectories. Various illustrative special solutions are obtained, particularly perturbation results valid for small thrust. For suface-to-surface rockets in a Kepler field, optimal thrust programs are obtained numerically, their accuracy is studied quantitatively, and comparison of range and of accuracy is made with rockets using a constant-angle thrust program. Optimization leads to only a slight increase in range but to a substantial gain in accuracy. The possible application of rocket optimization methods to the focusing of charged particles is also suggested.

OPTIMUM ROCKET TRAJECTORIES. II - GENERALIZED BOOST ANALYSIS. D. O. Dommasch and R. L. Barron. Aero/Space Engrg., Feb., 1960, pp. 45-58. Development of more general optimum boost relations than those considered previously on an initial value basis. The more general treatment considers aerodynamic effects and is based upon equations of motion referenced to the rotating navigational or earth great circle axis system. The results are obtained by using digital computer techniques for step-by-step integration of the optimum equation set starting from a given set of initial conditions. A comparison between arbitrary and optimum trajectories is presented, as well as a complete performance map describing the optimum boost performance of an advanced type of vehicle. To provide a completely valid analysis, all known influences on the trajectory have been considered, including aerodynamic lift and drag, as well as the forces required to maintain flight in a great circle plane fixed to the

rotating earth. The ARDC standard atmosphere is precisely simulated, the effects of gravitic potential change are included, and the kinematic equations and the equations of motion are satisfied precisely without any assumptions as to small perturbations.

LUNAR TRAJECTORIES. A. B. Mickelwait. ARS J., Dec., 1959, pp. 905-914. 35 refs. Review of the status of three-dimensional lunar trajectories and techniques for treating them analytically. The problem of a lunar satellite is treated in detail, considering equipment limitation and the interaction of trajectories and missions. Curves showing the interrelationship of flight parameters and also miss coefficients are presented.

TRAJECTORIES WITH CONSTANT TANGENTIAL THRUST IN CENTRAL GRAVITATIONAL FIELDS. W. E. Moeckel. US, NASA TR R-53, 1959. 96 pp. Calculation, in nondimensional form, of trajectories followed by vehicles propelled by a constant thrust directed parallel to the velocity vector for a range of initial thrust-weight ratios from 10 to 10^{-4} and for a range of jet velocities from those attainable with chemical rockets to infinity. The charts permit rapid calculation of propulsion time required to attain any prescribed hyperbolic velocity starting outward from a circular orbit, or to return to a circular orbit from any prescribed hyperbolic velocity. Results are given in the form of curves of radial distance, energy per unit mass (hyperbolic velocity), trajectory inclination, and velocity and angular distance as function of time. The use of these charts to estimate weight requirements for interplanetary missions is discussed.

DEPARTURE TRAJECTORIES FOR INTERPLANETARY VEHICLES. W. E. Moeckel. US, NASA TN D-80, Nov., 1959. 35 pp. Derivation of general expressions for the magnitude and direction of the launching velocity needed to reach another planet from any point on the Earth's surface. The effect of the inclination of the orbital plane of the destination planet is considered along with the effect of departure date and selected trajectory. A procedure is given for determining the optimum time of day for launching from any latitude to obtain maximum benefit of the Earth's rotation. Results of the analysis are illustrated for typical Earth-Venus trajectories.

AN ANALYSIS OF THE CORRIDOR AND GUIDANCE REQUIREMENTS FOR SUPERCIRCULAR ENTRY INTO PLANETARY ATMOSPHERES. Appendix A - FORMULAS FOR MOTION AND HEATING QUANTITIES AND RELATIONSHIP BETWEEN DECELERATION AND HEATING. Appendix B - INTERDEPENDENCE OF C_D AND L/D FOR LIFTING VEHICLES. D. R. Chapman. US, NASA TR R-55, 1959. 76 pp. Analysis of supercircular entry developed around a new dimensionless parameter which combines certain conditions at the conic perigee altitude with certain characteristics of the vehicle. This parameter conveniently determines either deceleration-limited or heating-limited corridor widths for elliptic, parabolic, or hyperbolic approach trajectories. Illustrative calculations of corridor widths and the associated guidance problems are presented for Venus, Earth, Mars, Jupiter, and Titan. Generalized curves are presented for application to various entry conditions.

OPTIMUM ARRANGEMENTS OF BOOST MOTORS IN MULTI-STAGE VEHICLES, FOR VERTICAL FLIGHT IN VACUO. H. Hiller. Gt. Brit., RAE TN G.W. 519, July, 1959. 19 pp. Presentation of an analytical method for finding optimum arrangements of a number of identical solid-fuel boost motors in a multi-stage vehicle which also carries a payload. Only vertical trajectories in vacuum are considered, and potential altitude is chosen as a criterion of performance. The optimum results for various ranges of the relevant parameters are given for up to 12 motors.

GUIDANCE TECHNIQUES FOR INTERPLANETARY TRAVEL. Ch. D. Bock and Ch. J. Mundo. ARS J., Dec., 1959, pp. 931-940. 36 refs. Study of the problem of guidance to near planets with low specific impulse engines. Trajectories to which the vehicle must adhere in order to minimize fuel consumption are treated in order to evolve what measurable parameters are suited for guidance. Criteria are established for the judging of suitability of these measurement parameters. Various possible measurement techniques are classified into active electromagnetic techniques, passive electromagnetic techniques, and inertial techniques. The merits of the individual methods and the classes are examined.

STABILIZATION AND ATTITUDE CONTROL OF SATELLITE VEHICLES. W. E. Frye and E. V. B. Stearns. ARS J., Dec., 1959, pp. 927-931. 41 refs. Review of the status of concepts and techniques in the field of satellite attitude control and stabilization as reflected in technical literature in the last five years. Stabilization by means of the gravity gradient, aerodynamic torques, and radiation pressure is examined. Various attitude sensors and control torque generators are discussed. The sources of disturbing torques are briefly summarized.

THE ALLOCATION OF THE CONTROL MAGNITUDE FOR AXISYMMETRICAL MISSILE. Akira Azuma. Japan Soc. Aero. & Space Sci. Trans., No. 2, 1959, pp. 35-48. Analysis of a method for allocating the control magnitude to each control surface for either fin-stabilized or spinning missiles with four fins having rotational and mirror symmetry. It is shown that the allocation is simple for the fin-stabilized or roll-stabilized missiles as compared with the freely spinning missiles having no constrained action for spinning motion. For a free-spin missile with four fins, the allocation of a given control magnitude to each control surface is proportional to the cosine and sine components of the rolling angle. The maximum lift component normal to the spin axis is described as a regular square, the largest

value being located at the direction making an angle of $\pi/4$ with each orthogonal main surface or fin. For rapidly forced spinning projectiles or missiles, the dynamic treatment reveals a phase difference between the direction of the control surface deflection and the resulting trimmed angle of attack.

SOME NOTES ON ATTITUDE CONTROL OF EARTH SATELLITE VEHICLES. Appendix A - STABILITY OF SPINNING BODIES. Appendix B - PITCH RESPONSE FOR SATELLITE STABILIZED BY GRAVITATIONAL-GRADIENT METHOD, NO DAMPING. Appendix C - CIRCULAR ORBITS THAT PERMIT A CONTINUOUS VIEW OF THE SUN. Appendix D - MOMENTUM, TORQUE, AND POWER OF ANGULAR MANEUVERS. Appendix E - WEIGHT AND POWER REQUIRED BY FLYWHEEL CONTROL UNITS. Warren Gillespie, Jr., D. G. Eide, and A. B. Churgin. US, NASA TN D-40, Dec., 1959. 80 pp. 31 refs. Investigation of the problem of matching satellite mission stabilization requirements with attitude control system capabilities. The probable missions in an advanced satellite program and a variety of possible satellite stabilization systems are considered. The methods are compared with respect to mission suitability, accuracy, weight, power requirements, development effort, and reliability. An improved version of spin stabilization incorporating earth-horizon scan units is described, and recommendations are made for radiation-sensing systems.

PRECISION ORBITS AND OBSERVATION REDUCTION. Samuel Herrick. U. Calif. UCLA Astrodynamical Rep. 1 (AFOSR TN 59-769), June 11, 1959. 21 pp. USAF-Army-Navy-supported discussion of the advantages and disadvantages in the reduction of observations of "fixes," triangulation, assumed motions or orbits, reduction to the center of the earth, and reference systems. The differential correction is defined and outlined. The "fix" and "complete observations" are discussed in relation to the determination of orbits and compared with the differential correction. The provinces of observer and orbit analyst are differentiated. The need for accurate observations and reductions is stressed.

DIFFERENTIAL EXPRESSIONS FOR LOW-ECCENTRICITY GEOCENTRIC ORBITS. Samuel Herrick, L. G. Walters, and C. G. Hilton. U. Calif. UCLA Astrodynamical Rep. 2 (AFOSR TN 59-768), June 11, 1959. 33 pp. Development of differential equations relating the set of six two-body orbit parameters to rectangular components of position and velocity, the latter being necessary to the evaluation or orbital and re-entry flight conditions. These differential expressions are extended to the observational framework employed in the range. This is carried out for radar-type instruments where the emphasis is on very accurate range and range-rate data.

REFLECTION CHARACTERISTICS OF ARTIFICIAL SATELLITES CONSTRUCTED IN THE FORM OF INFLATED POLYHEDRONS. A. R. Sinclair. US, NASA TN D-174, Dec., 1959. 9 pp. Description of tests made on inflated polyhedral shapes of thin aluminum-coated plastic to determine their suitability as artificial earth satellites having enhanced visibility as a result of bright flashes of reflected light from the facets. It was found that a polyhedron with 12 major faces, when inflated as a simple balloon, gives about one flash per revolution about a random axis when illuminated by a light representing the sun. As a result of the bulging of the facets, the brightness of these flashes was only about three times greater than that from an equivalent sphere, which is much less than the theoretical brightness from a polyhedron having optically flat facets.

Spacecraft

A NEW COORDINATE SYSTEM FOR SATELLITE ORBIT STUDY. Appendix - A MORE ACCURATE SOLUTION OF THE SECOND EQUATION OF MOTION. J. L. Brenner, G. E. Latta, and M. Weisfeld. SRI ITR 2 (AFMDC TR 59-27) [AD 216455], June 15, 1959. 85 pp. Presentation of a method predicting accurately the orbit of a near-earth satellite, neglecting drag. The coordinate system suggested by King-Hele is refined so as to make predictions within a few seconds of arc at all points in the orbit of a typical satellite. The order of approximation of the formulas is discussed by the use of arguments based on the energy integral, and their accuracy is verified by independent numerical integration of the differential equations. The principal effects of oblateness are listed, and it is shown that the maximum latitude attained by the satellite varies a small amount from revolution to revolution, with the same period.

EFFICIENT PRECISION ORBIT COMPUTATIONAL TECHNIQUES. R. M. L. Baker, Jr., G. B. Westrom, C. G. Hilton, J. L. Arsenault, R. H. Gersten, and Elsie Browne. U. Calif. UCLA Astrodynamical Rep. 3 (AFOSR TN 59-766), June 11, 1959. 72 pp. 22 refs. USAF-Army-supported comparison of the methods of Cowell, Encke, and the variation-of-parameters for the computation of high precision orbits. Analysis of the integration of an analytical three-body trajectory and an analytical low-thrust spiral trajectory indicates the importance of decreasing the overall number of integration steps to avoid round-off errors. Comparative computations demonstrated that Encke's method is preferable to the ballistic lunar trajectory, variation-of-parameters in the low-thrust trajectory, and Cowell's method in the high-thrust trajectory. The overall computational efficiency of Encke's and the variation-of-parameters method is also shown.

OPTIMAL PROGRAMMING AND CONTROL OF SATELLITE ORBITS. C. A. Traenkle. ZFW, Nov., 1959, pp. 305-313. Presentation of an approach, using the methods of reference trajectories, to the problem of putting a satellite into orbit. The reduction of the take-off weight attained by appropriate launch programs, in particular by tangential ascent combined with skim launching, is discussed. Compared with the conventional zero

angle of attack launch program, the payload may be increased for a given take-off weight by a factor which depends on the launch angle and is considerably greater than two for extreme cases. The investigation is extended to cover the descent mechanics, including the design of optimal programs and an analysis of proximity and skim orbits, as applied to intermediate and long range haul.

THE DETERMINATION OF THE EARTH'S POTENTIAL FIELD BY OBSERVATIONS OF SATELLITE ORBITS, WITH SPECIAL REFERENCE TO THE DETERMINATION OF THE THIRD HARMONIC. J. L. Brenner, R. Fulton, and N. Sherman. SRI ITR 3 (AFMDC TR 59-29), July 1, 1959. 36 pp. Analysis of the differential equations of motion of a near-earth satellite about a model earth having mass distribution which is symmetric with respect to its polar axis and its equatorial plane reveals that the satellite's orbit undergoes long-period changes not previously reported. Numerical integration of the equations of motion verifies this result. These changes are minute and definitely observable only if many observations are made during each revolution. On the other hand, a bias in the handling of the observations can override these changes, and introduce spurious secular (long-term) variations. The magnitudes and periods of typical spurious variations have been evaluated. The variation of the eccentricity agrees with that reported from the Vanguard computing center; hence, its use in verifying the existence of a third harmonic in the earth's gravitational potential field is not justified.

NEARLY CIRCULAR TRANSFER TRAJECTORIES FOR DESCENDING SATELLITES. G. M. Low. US, NASA TR R-3, 1959. 17 pp. Supt. of Doc., Wash., $0.30. Derivation of simplified expressions describing the transfer from a satellite orbit to the point of atmospheric entry. The expressions are limited to altitude changes that are small compared with the earth's radius and velocity changes small compared with satellite velocity, and further restricted to motion about a spherical, nonrotating earth. The transfer trajectory resulting from the application of thrust in any direction at any point in an elliptic orbit is considered. Expressions for errors in distance (miss distance) and entry angle, due to an initial misalignment and magnitude error of the deflecting thrust, are presented. The guidance and accuracy requirements to establish a circular orbit are discussed along with orbit corrections.

AIR SCOOPING VEHICLE. Appendix A, B - LAMINAR HEAT TRANSFER RATE TO THE SIDE WALL OF THE VEHICLE. Appendix C - ACCOMMODATION OF THE INCIDENT ENERGY. Appendix D - THE LIQUEFACTION AND STORAGE OF ATMOSPHERIC GASES. Appendix E - EVALUATION OF THE BOUNDARY LAYER MOMENTUM AND ENERGY THICKNESS IN THE MHD ISOTHERMAL ACCELERATOR. Felix Berner and Morton Camac. Avco Everett Res. Lab. RR 76 (AFBMD TR 59-17), Aug., 1959. 117 pp. 17 refs. Description of a satellite vehicle which collects gases from the upper atmosphere and stores them in liquid form. Such a vehicle could serve as a filling station in space, furnishing liquid oxygen or air to other spacecraft. The vehicle represents an alternative to launching these liquids into orbit from the surface of the earth. The two methods are compared on an economic basis, and it is shown that the proposed vehicle permits substantial savings when operated beyond about one year. The feasibility of developing such a system for long-time operation is investigated. Several practical designs are discussed.

NAVIGATION

CELESTIAL GUIDANCE. R. B. Horsfall. ARS J., Dec., 1959, pp. 981-988. Study of the problems in automatic celestial guidance for cruise vehicles. The equations for the error signals are derived from star tracking based on an assumed possition and local vertical reference. The problem of distinguishing a star from a noise background is also treated, and the problem of directing the telescope from a reference is examined both from the point of view of astronautics and cruise missile guidance.

VECTOR PRINCIPLES OF INERTIAL NAVIGATION. Appendix I - DERIVATION OF VECTOR MECHANIZATION EQUATION WITHOUT IMPOSING THE INERTIAL AZIMUTH CONDITION. Appendix II - THE VERTICAL CHANNEL AND INERTIALLY MEASURED ALTITUDE. Appendix III - NOTES ON DERIVATION OF CERTAIN EQUATIONS. Appendix IV - PROPERTIES OF THE SAMPLE SYSTEM. Appendix V - DERIVATION OF A SCHULER OSCILLATION EFFECT. A. M. Schneider. IRE Trans., ANE Ser., Sept., 1959, pp. 159-178. Derivation of a vector equation describing the mechanization of inertial navigation systems for use anywhere in space. A specialized form of this equation applies directly to three-dimensional motion at any speed, any altitude, over an elliptical, rotating earth. Behavior of errors in inertial systems is also discussed.

PRINCIPLES OF DOPPLER-INERTIAL GUIDANCE. L. H. Dworetzky and A. Edwards. ARS J., Dec., 1959, pp. 967-972. 20 refs. Discussion of the principles of the Doppler-inertial system theory, and description of the characteristics and limitations of individual Doppler radar and inertial navigation systems. One of the most important features of the combined system is that it can establish its orientation in a navigational reference frame without ground alignment or dependence upon a magnetic compass. It erects itself to the vertical and can align itself to true north while in flight. The choice of values for the damping, tuning, and third-order integrator gains in the combining equipment is based on consideration of the transient response to disturbances, particularly errors in the inertial system's initial conditions, and consideration of the effects of system noise and bias errors on the outputs.

Electronic Aids

DOPPLER RADARS FOR GUIDANCE - DESIGN TECHNIQUES AND PERFORMANCE. W. R. Fried. ARS J., Dec., 1959, pp. 957-967. 54 refs. Description of the fundamental principles of self-contained Doppler velocity measuring radars and Doppler guidance systems. A comparison of the various design techniques for Doppler radars and the advantages and limitations of each are presented. The overall configuration of a typical Doppler radar is described, and the performance characteristics with regard to accuracy and range capabilities are discussed. It is shown that basic velocity information with a probable error of near 0.1% is obtainable from the Doppler radar. The use of Doppler radar as one element of a complete guidance system is discussed. The overall system accuracy of such a system is shown to be a function of the accuracies of all the sensor and computation elements and, in many cases, can be no better than that of the weakest element. The nature of some of the system errors is described, including the effects of the directional and attitude references.

NUCLEAR ENERGY

THE CALCULATION OF GAS FLOW PASSAGE SIZES IN HEAT EXCHANGERS AND NUCLEAR REACTORS WHEN THE HEAT TRANSFER REQUIREMENTS AND THE GAS INLET AND OUTLET TEMPERATURES ARE SPECIFIED. Appendix I, II - DERIVATION OF THE APPROXIMATE EXPRESSIONS FOR PRESSURE LOSS. Appendix III - THE RELATIONSHIP BETWEEN PUMPING POWER AND FRACTIONAL PRESSURE LOSS. Appendix IV - DERIVATION OF THE EXPRESSIONS FOR THE MAXIMUM SURFACE TEMPERATURE IN A REACTOR CORE WITH A NON-UNIFORM NEUTRON FLUX DISTRIBUTION. J. F. Barnes. Gt. Brit., NGTE Memo. M.328, Aug., 1959. 41 pp. Presentation of an approximate treatment for the determination of heat exchanger scantlings and definition of a simplified model of a gas cooled reactor core to which this analysis can be applied. Modifications are introduced to allow for sources of pressure loss other than skin friction and heat addition and to take account of features peculiar to reactors - i.e., nonuniformity of heat release within the core. The calculation of pressure losses due to friction and heat addition is dealt with in more detail, and a description is given of a step-by-step method for solving the basic differential equation for one-dimensional flow in a constant area passage. Graphs of pressure loss are presented for air (or nitrogen), and methods are suggested for using these to estimate the detailed heat transfer performance of a reactor. Similar data for helium or other gases may be compiled easily by the same methods with the aid of a digital computer.

POWER PLANTS

ION PROPULSION SYSTEMS: EXPERIMENTAL STUDIES. Sam Naiditch, R. M. Worlock, D. Zuccaro, D. Baker, M. P. Ernstene, L. R. Gallagher, J. Mullins, and J. A. Teem. ARS 14th Annual Meeting, Wash., Nov. 16-20, 1959, Preprint 928-59. 55 pp. 21 refs. Army-supported discussion of problems encountered in the development of ion propulsion devices and analysis of the progress on various components of ion motors. Includes description of experiments on both porous tungsten and staggered ribbon ion sources; measurements of the effective area of the staggered ribbon and correlation with an analytical study; research on two types of accelerators - parallel-plate and Pierce-type; analytical and analog studies of ion flow, using an elastic membrane potential analog and an electrolytic tank to study the defocusing effects of the electrode apertures through which the beam passes; detailed analyses of neutralization by both electrons and charge exchange, based on a highly idealized model of the experimental system.

Rocket

A ONE-DIMENSIONAL THEORY OF LIQUID-FUEL ROCKET COMBUSTION. D. B. Spalding. Gt. Brit., ARC CP 445, 1959. 26 pp. BIS, New York, $0.72. Study of a one-dimensional theoretical model of a liquid rocket engine in which all properties depend only on distance from the injector face and droplets have uniform diameter on entry. The processes considered cover droplet drag, vaporization, and chemical reaction. The derived equations are integrated, leading to predictions of the minimum rocket length made for the particular case in which the chemical reaction rate is high and the fuel and oxidant, though ejected separately, have similar droplet properties. Calculations are made of the effects of droplet size, droplet injection velocity, final gas velocity, droplet transfer number, and other variables. The mean residence time and the concentration-time curve of an injected tracer are also calculated.

A ONE-DIMENSIONAL THEORY OF LIQUID-FUEL ROCKET COMBUSTION. II - THE INFLUENCE OF CHEMICAL REACTION. J. Adler. Gt. Brit., ARC CP 446, 1959. 14 pp. BIS, New York, $0.45. Study including integration of differential equations resulting from Spalding's one-dimensional liquid rocket combustion model and derivation of temperature and velocity profiles for the fuel droplets. A simple approximate procedure for solving the equations is also given, providing good results when compared with exact integration.

ANALYSIS OF THE TRANSIENT RADIATION HEAT TRANSFER OF AN UNCOOLED ROCKET ENGINE OPERATING OUTSIDE EARTH'S ATMOSPHERE. W. H. Robbins. US, NASA TN D-62, Dec., 1959. 25 pp. Derivation of relations for the cooling rate of a body in space. The rate of radiant heat dissipation (reflected by the temperature) is determined to be a function of material properties of the body, the geometry of the body, and the temperature of both the body and the effective surrounding temperature. Application of the results is made to the uncooled (heat sink) high-chamber-pressure rocket engine. Cooling times from the temperature at burnout to a specified fi-

nal temperature are presented for a range of thrusts and running times. In general, the cooling time increases almost linearly with running time.

RESEARCH, RESEARCH FACILITIES

Wind Tunnels

ANALYTICAL STUDY OF THE HEATING OF HYPERSONIC AIR FLOW BY ELECTRODE-LESS HIGH-FREQUENCY DISCHARGE. J. C. Williams, III, P. C. Wilber, and R. L. Chuan. USAF AEDC TR 59-23, Oct., 1959. 67 pp. 24 refs. Study of the possibility of heating a supersonic gas stream by means of electrodeless high-frequency discharge. The heating scheme is divided into two parts: the discharge where energy is added to the gas stream and stored as potential energy of electron-ion separation, and the decay where the electrons and ions recombine and give up some of the separation energy as thermal energy of the gas. Qualitative consideration of the discharge phase indicates the necessary relations between the electric field parameters, the hydrodynamic parameters, and the chamber dimensions for an efficient discharge. Finally, it is shown how high-frequency electrodeless discharge heating might be applied practically to the heating of a low-density, high Mach Number, wind tunnel gas stream.

ROTATING WING AIRCRAFT, HELICOPTERS

DYNAMIC-MODEL INVESTIGATION OF THE DAMPING OF FLAPWISE BENDING MODES OF TWO-BLADE ROTORS IN HOVERING AND A COMPARISON WITH QUASI-STATIC AND UNSTEADY AERODYNAMIC THEORIES. M. A. Silveira and G. W. Brooks. US, NASA TN D-175, Dec., 1959. 30 pp. Description of a systematic investigation of the deficiency in damping of rotor blades operating at low rotor inflow velocities. Results show that the total damping, when plotted as a function of the ratio of blade bending frequency to rotor speed, fluctuates between upper and lower bounds given by combined quasi-static aerodynamic and structural damping and by structural damping, respectively. The reductions in damping are consistent with trends predicted by existing two-dimensional unsteady aerodynamic theory.

STRUCTURES

Beams & Columns

TORSION OF BEAMS WHOSE SECTIONS ARE BOUNDED BY CERTAIN QUARTIC CURVES. W. A. Bassali. J. Mech. & Phys. Solids, Oct., 1959, pp. 272-281. 17 refs. Application of Cauchy integral methods to the torsion of a solid isotropic cylinder whose section is bounded by a quartic curve which is the inverse of an ellipse with respect to any point on its major or minor axis. The complex torsion function, the torsional rigidity, and the shearing stresses are explicitly determined in the general case, and particular values are found to agree with those already known for Booth's lemniscate and the elliptic limacon. The distribution of shearing stress on the boundary is computed in two particular examples.

Cylinders & Shells

ON THE SOLUTION OF A CLASS OF PROBLEMS IN MEMBRANE THEORY OF THIN SHELLS. E. Reissner. J. Mech. & Phys. Solids, Oct., 1959, pp. 242-246. ONR-supported analysis of a class of problems in which the meridional and circumferential stress resultants are proportional to cos θ. Illustrations are given by solving the problem of flexure of a cantilever shell, as well as the problem of a shell with hydrostatic lateral load. The formulas for the latter case are specialized to the form which they assume for an ellipsoidal shell to enable comparison with an earlier solution of this problem.

PLASTIC BUCKLING OF CYLINDRICAL SHELLS. S. Radhakrishnan. Aircraft Eng., Dec., 1959, pp. 365-372. Extension of the work started by Gerard along the lines initiated by Stowell. The procedure used for the derivation of the basic equations of equilibrium for the case of plastic buckling is quite similar to that used for the buckling problem in the elastic case except for two significant differences: (1) choice has to be made as to the suitable stress-strain relation to be used in the plastic region, (2) assumptions have to be made as to whether some portions of the material get into elastic regime during the process of buckling. Stowell's work on plates using the assumption that no elastic unloading took place gave good check with experimental results and the present analysis carries the same assumption. The numerical results show that for certain ratios of axial compressive stress to circumferential compressive stress, the critical values are higher than even the pure axial load case. In the cases of cylinders under pure torsion or lateral pressure, the theoretical predictions by the present theory give fair agreement with experimental results. However, it remains to be seen whether the theoretical predictions are valid under the combined loads such as axial tension or compression combined with lateral pressure.

Plates

OBLICZANIE POWIERZCHNI WPŁYWOWYCH DLA PŁYT RÓWNOLEGŁOBOCZNYCH. Marian Suchar. Rozprawy Inżynierskie, No. 2, 1959, pp. 235-260. 16 refs. In Polish, with summaries in English and Russian. Calculation of influence surfaces (Green's functions) for plates having the form of parallelograms. The assumptions are those made for thin plates with small deflections stating that the plate is homogeneous, anisotropic, perfectly elastic, and has at every point one plane of elastic symmetry parallel to the middle plane. The relations between the deflection and the cross-section quantities are derived, as well as the differential equation of the deflection surface in the case of anisotropy and orthotropy. The boundary conditions are formulated in the simplest cases of support. The singular parts of the influence surface

of deflection are computed for anisotropic, orthotropic, and isotropic plates in orthogonal coordinates. A system of polynomials is then given, by which regular parts of the influence surfaces may be determined. Finally, a numerical example is considered, and diagrams of contour lines of the influence surfaces for the bending moment, the twisting moment, and the shearing force are presented.

Sandwich Construction

CALCULATED EFFECTIVE THERMAL CONDUCTIVITIES OF HONEYCOMB SANDWICH PANELS. R. T. Swann. US, NASA TN D-171, Dec., 1959. 24 pp. Calculation of steady-state temperature distribution through honeycomb panels with simultaneous radiation and conduction. Based on this temperature distribution, the heat which will be transmitted is calculated. An effective thermal conductivity is defined, and calculated results are presented in dimensionless form. The effect of heat transmission through the air in cells is briefly considered. The calculated results are compared with available experimental results.

Thermal Stress

OPTIMUM DESIGN OF INSULATED TENSION MEMBERS SUBJECTED TO AERODYNAMIC HEATING. J. R. Davidson. US, NASA TN D-117, Dec., 1959. 38 pp. Presentation of a method for determining the weight efficiency of insulated heat-sink structures, used for finding the lightest total structural weight for any selected insulating and load-carrying material in terms of a load parameter which accounts for the load, insulation material, and flight time. Charts are presented for six material as a function of the load parameter and the temperature of the aerodynamically heated side of the insulation.

THERMODYNAMICS

Combustion

PRESSURE AND VELOCITY MEASUREMENTS ON DETONATION WAVES IN HYDROGEN-OXYGEN MIXTURES. D. H. Edwards, G. T. Williams, and J. C. Breeze. J. Fluid Mech., Nov., 1959, pp. 497-517. 26 refs. Measurements of the static pressures and velocities of detonation waves, emphasizing the pressures arising from the normal reflection at the closed end of the explosion tube. Two explosion tubes, of 10- and 1.6-cm. diam. are employed to study the diameter effect on the wave pressures. The experimental results are compared with calculated values of the wave properties for a range of hydrogen-oxygen mixtures initially at atmospheric pressure. In the 10-cm. tube the static pressures and velocities are found to agree well with theory for mixtures with hydrogen content in the approximate range 50-75%; the evidence from the pressure profiles and wave velocities indicates that mixtures outside this range may not be able to support ideal Chapman-Jouguet waves. Static pressure records in the 1.6-cm. tube show relatively rapid decay of the pressure following the initial peak. Furthermore, the measured velocities are all less than ideal values, the deviations being greater for extreme compositions. A possible explanation of the discrepancy between experiment and theory, in terms of energy loss to the tube wall, is discussed.

ON THE STABILITY OF A PLANE DEFLAGRATION WAVE. J. Menkes. Royal Soc. (London) Proc., Ser. A, Dec. 15, 1959, pp. 380-389. Army-sponsored analysis of the stability of a one-dimensional deflagration wave to small disturbances. By introducing a suitable approximation to the steady-state temperature distribution, and after assuming that the Lewis Number of the umperturbed flow is unity, it is possible to obtain an explicit solution to the disturbance equation. It is demonstrated that within the framework of the present analysis the deflagration wave appears to be stable.

ON THE EXISTENCE OF STEADY STATE FLAMES. A. L. Berlad and C. H. Yang. (Comb. Inst. West. States Sect. Meeting, June, 1958.) Comb. & Flame, Dec., 1959, pp. 447-452. Examination of the adiabatic flame theories showing that the conditions, "adiabatic" and "steady state," imposed on the flame model are contradictory when a realistic reaction rate law is used. For the case of a freely propagating flame, only a quasi-steady state can be achieved, even though the "adiabatic" condition is removed. Mathematically, this quasi-steady state can be described by a steady-state temperature profile coupled with a moving source near the "cold boundary" in such a way that both the temperature profile and the moving source propagate at the same velocity.

THEORY OF THE BURNING OF MONOPROPELLANT DROPLETS. F. A. Williams. (Comb. Inst. West. States Sect. Winter Meeting, Pasadena, Jan. 20, 1958.) Comb. & Flame, Dec., 1959, pp. 529-544. 24 refs. Army-sponsored analysis considering the steady-state burning of a single liquid monopropellant droplet in an infinite inert atmosphere, including allowances for thermal conduction, diffusion, and chemical kinetic effects. An approximate analytical expression for the burning rate is derived for the case in which the activation energies of all important reactions are large. Simplified forms of the governing equations are given for one-step reactions with specific boundary conditions and a Lewis Number of unity. A numerical integration of the governing equations for second-order reactions is performed for adiabatic burning, and an analytical correlation of the resulting burning rate as a function of droplet radius at low activation energies is presented. Comparison is made with experiment, and the results are discussed.

THEORY OF THE BURNING OF MONO-PROPELLANT DROPLETS. D. B. Spalding and V. K. Jain. Gt. Brit., ARC CP 447, 1959. 13 pp. BIS, New York, $0.45. Derivation of formulas for the burning rate and time of monopropellant droplets suspended in an atmosphere of their own decomposition products. The assumption of a constant liquid temperature and a high activation energy of the reaction is introduced. Some experimental data for qualitative support of the theory are presented.

One of a series

On the riddle of rolling friction

It doesn't take much to roll a hard ball across a hard, smooth, level surface – actually only about 0.00001 times the normal force acting vertically on the ball. But by careful measurement of this tiny rolling force, scientists at the General Motors Research Laboratories are helping to unravel the riddle of rolling friction.

An important relationship recently uncovered in this fundamental study: the rolling force is proportional to the volume of material that is stressed above a certain level. As a result, a GM Research group have not only confirmed the hypothesis of *how* a rolling ball loses energy (Answer: elastic hysteresis) but also have learned *where* this lost energy is dissipated (Answer: in the interior of the material, not on the surface). Mathematical analyses have indicated the exact shape of the elastically stressed volume in which all the significant frictional loss takes place.

The purpose of friction research at the GM Research Laboratories is to learn more about the elastic and inelastic behavior of materials. This knowledge – of academic interest now – will eventually give GM engineers greater control of energy lost through friction. This is but one more example of how General Motors lives up to its promise of "More and better things for more people."

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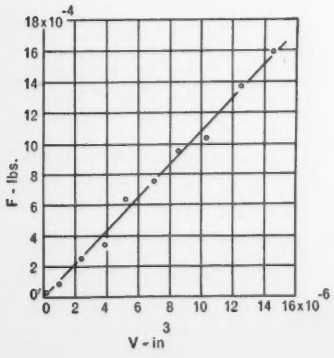

Relationship of rolling force to elastically stressed volume.

mat., No. 1, 1959, pp. 136–144. In Russian. Determination of certain properties of second-order surfaces in an elliptical space.

Algorifmicheskie Operatory v Konstruktivnykh Polnykh Separabel'nykh Metricheskikh Prostranstvakh. G. S. Tseitin. *AN SSSR Dokl.*, Sept. 1, 1959, pp. 49–52. In Russian. Determination of the properties of algorithmic operators in constructive, complete, separable metric spaces.

Transforms

On the Double Laplace Transforms of Some Green's Functions. James Radlow. *J. Math. & Phys.*, Oct., 1959, pp. 203–205. USAF-sponsored research.

A General Method to Find the Laplace Transform of an Arbitrary Function Cut Off at an Arbitrary Point. Shin'ichiro Takeda. *Hosei U. Tech. Coll. Rep. 4*, Aug., 1959, pp. 1–11.

A Theorem on Integral Transforms with an Application to Prediction Theory. J. Chover. *J. Math. & Mech.*, Nov., 1959, pp. 939–945. Army-Navy-supported study.

Laplace Transform of Exponential Function Whose Index Includes Sine or Cosine Function. Keisuke Onuma. *Hosei U. Tech. Coll. Rep. 4*, Aug., 1959, pp. 20–28.

Mechanics

On a Problem of Nonlinear Mechanics. D. G. Magiros. *Info. & Control.* Sept., 1959, pp. 297–309. 10 refs. Analysis of a forced oscillatory system which is linearly damped but nonlinear in the restoring force.

Ob Ustoichivosti Periodicheskikh Dvizhenii v Sluchae Dvukh Nulevykh Kornei. S. V. Kalinin. *Prikl. Mat. i Mekh.*, Sept.-Oct., 1959, pp. 975–977. In Russian. Extension of a previously developed method to the calculation of stability of periodic motions for the case involving two zero roots.

Preliminary Survey of High-Speed Impact Information. P. A. Franken. *USAF WADC TR 58-577 [AD 216029]*, June, 1959. 24 pp. 17 refs.

K Teorii Kolebanii Uprugikh Tel, Imeiushchikh Zhidkie Polosti. N. N. Moiseev. *Prikl. Mat. i Mekh.*, Sept.-Oct., 1959, pp. 862–878. In Russian. Presentation of an approximate theory on the vibration of elastic bodies having cavities filled with liquid. The assumptions introduced into the study are presented along with general equations, spectral analysis, and variational principles.

Meteorology

Studies Relating to Condensation Trails. *Carnegie Inst. Tech. Dept. Mech. Eng. Final Rep. (AFCRC TR 59-257)*, July, 1959. 67 pp. 15 refs. Presentation of three studies on condensation trail phenomena. The first is on experimental determination of the effect of hygroscopic nuclei on the size and concentration of water drops in a contrail. The second is a numerical evaluation of the equations of drop growth. In the third, a new theory of nuclei growth is presented, based on the kinetic theory of gases.

The Acceleration of Water Drops by an Airstream of Constant Relative Velocity. D. C. Jenkins. *Gt. Brit., RAE TN Mech. Eng. 293*, May, 1959. 13 pp.

Vliianie Izmeneniia Vertikal'noi Sostavliaiushchei Skorosti Vetra na Obrazovanie Livnevykh Osadkov i Grada. N. Sh. Bibilashvili, A. M. Zaitseva, V. F. Lapcheva, A. A. Ordzhinokidze, and G. K. Sulakvelidze. *AN SSSR Dokl.*, Sept. 21, 1959, pp. 521–524. In Russian. Discussion covering the effect of variation of the vertical component of wind velocity on the formation of rain precipitations and hail.

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The Theory of Locally Isotropic Turbulence. A. S. Monin. *Sov. Phys. - Dokl.*, Oct., 1959, pp. 271–274. Translation. Presentation of an approach to locally isotropic turbulence which yields more precise derivations of known results and leads to new results.

Winds and Wind Structure at 100,000 Feet from Constant Altitude Balloon Trajectories. Appendix A—**Trajectories of IGY Balloon Flights.** Appendix B—**Three-Hour-Average Velocities from Constant Altitude Balloon Flights.** H. T. Mantis. *U. Minn. Sch. Phys. Dept. Mech. Eng. Final Sci. Rep. (AFCRC TR 59-243) [ADZ14594]*, Apr., 1959. 84 pp.

Radio Echo of Certain Invisible Objects of the Troposphere. A. G. Gorelik and V. V. Kostarev. *Sov. Phys. - Dokl.*, Oct., 1959, pp. 319–321. Translation. Recording of radar echos and analysis of these results to establish some relations between the data from radio-location soundings and the meteorological conditions.

Synoptic Application of Dynamical Concepts. Appendix I—**Measurements of Horizontal Divergence and Vertical Velocity,** G. B. Brown and Frederick Sanders. Appendix II—**Some Relationships Between Air Mass Stability, Large-Scale Vertical Motion and Thunderstorm Frequency,** A. J. Wagner and Frederick Sanders. Appendix III—**Some Linear Estimates of the Predictability of Precipitation,** T. M. Noel and Aaron Fleisher. Appendix IV—**Ceiling and Visibility Fluctuations,** Morton Glass and J. M. Austin. *MIT Dept. Meteorology Final Rep. (AFCRC TR 59-227) [AD 212267]*, Feb. 28, 1959. 92 pp. 25 refs.

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Horizontal Diffusion in the Atmosphere as Determined by Geostrophic Trajectories. C. S. Durst, A. F. Crossley, and N. E. Davis. *J. Fluid Mech.*, Oct., 1959, pp. 401–422. 13 refs.

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Comparison of Various Conditioning Methods for Rawinsonde Balloons; Results from the South Pole Station, Antarctica, 1957. E. C. Flowers and H. Hansen. *Mo. Weather Rev.*, July, 1959, pp. 261–267.

Missile, Rocket, & Space Technology

Missiles 1959. *Flight*, Nov. 6, 1959, pp. 507–516. Survey of ballistic, aerodynamic cruise, battlefield, air-to-surface, antisubmarine, surface-to-air, and air-to-air missiles presenting the development program and design characteristics.

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Automatic Checkout and Alarm Monitoring; Some Basic Design Considerations. B. K. Smith. *Missile Des. & Devel.*, Nov., 1959, pp. 36, 37. Discussion of methods to improve checkout systems considering the following basic characteristics which define information: change, rate of change, direction of change relative to present operating point, and change from a predictable normal operating pattern.

Mobile Range Instrumentation for Point Mugu. Peer Fossen. *GSE*, Oct.-Nov., 1959, pp. 92–94, 96. Description of portable equipment for missile flight control and flight data storage for later reduction and analysis.

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The Determination of Space Orientation and Length of an Elongated Object from Series of Long Focus Photographs. H. K. Eichhorn. *RCA Data Proc. TR 51 (AFMTC TR 59-19)*, Sept. 4, 1959. 35 pp.

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REVIEWS OF Books

. . . in the field of aeronautical engineering and space technology

AERODYNAMICS

Foundations of Aerodynamics. A. M. Kuethe and J. D. Schetzer. 2nd Ed. New York, John Wiley & Sons, Inc., 1959. 446 pp., illus., diagrs., tables, folding chart. $11.75.

Since the base of aerodynamic foundations has broadened considerably in the 9 years since the original publication of this text, the present edition has been extensively revised to include some of the important topics on which recent technological advances are based. The chapter on energy relations has been rewritten, and the treatment of one-dimensional compressible flows has been expanded to include sections on heat addition. The material on wings in compressible flow is now presented from the point of view of lifting surface theory. A major revision of the material on viscous fluids greatly expands the discussion of compressibility in both laminar and turbulent flow. The coverage of isotropic turbulence has been reduced to that considered adequate for an understanding of the concept of turbulent shearing stress and its role in establishing turbulent shear flow. Real gas effects at high altitudes and temperatures are introduced in an appendix.

In addition to these major changes, new problems and graphical material have been added, and all charts and tables have been grouped together in the back of the book for convenience in problem solving. Finally, the material on aerodynamic characteristics of wings, which formerly appeared in Chapter 18, and additional comparisons between theory and experiment have been included in an appendix.

The authors are, respectively, Felix Pawlawski Professor of Aerodynamics and Professor of Aeronautical Engineering, University of Michigan.

Turbulent Flows and Heat Transfer. C. C. Lin, Editor. (High Speed Aerodynamics and Jet Propulsion, Vol. 5.) Princeton, N.J., Princeton University Press, 1959. 549 pp., illus., diagrs., tables. $15.

Contents: Transition from Laminar to Turbulent Flow, H. L. Dryden. Turbulent Flow, G. B. Schubauer and C. M. Tchen. Statistical Theories of Turbulence, C. C. Lin. Conduction of Heat, M. Yachter and E. Mayer. Convective Heat Transfer and Friction in Flow of Liquids, R. G. Deissler and R. H. Sabersky. Convective Heat Transfer in Gases, E. R. van Driest. Cooling by Protective Fluid Films, S. W. Yuan. Physical Basis of Thermal Radiation, S. S. Penner. Engineering Calculations of Radiant Heat Exchange, H. C. Hottel.

Basic Data of Plasma Physics. Sanborn C. Brown. Cambridge, Mass., The Technology Press of The Massachusetts Institute of Technology; New York, John Wiley & Sons, Inc., 1959. 336 pp., diagrs., tables. $6.50.

The present volume is a combination of Professor Brown's class notes and of data included in an M.I.T. technical report on basic data of electrical discharges (*Research Laboratory of Electronics Report No. 283*), and was prepared specifically for an M.I.T. course in plasma dynamics given during the summer of 1959. The whole emphasis of the book is on the fundamental processes, with the necessary data and background information given in the form of graphs and tables. Devices are discussed only as illustrations of the fundamental physics of the motion of charged particles.

AERONAUTICS, GENERAL

Proceedings of Sixth Technical Conference of Rosemount Aeronautical Laboratories, October 1959. (Research Report No. 165.) Minneapolis, University of Minnesota, 1959. 461 pp., illus., diagrs., tables.

Contents: (1) Hypersonic Flow Regimes at the Re-Entry of Satellite Vehicles, R. Hermann. (2) Solar Radiations in Space, J. M. Lagerwerff. (3) Fuel Energy Management, E. G. Domich. (4) Theory of Ground Interference on Rocket Sleds, R. Hermann, W. L. Melnik, and J. Yalamanchili. (5) Experimental Investigation of the Aerodynamics of Supersonic Sleds, R. Hermann and F. A. Moynihan. (6) Analysis and Wind Tunnel Investigation of Some Ram Tunnel Operation Problems, R. Hermann, K. O. Thompson, and L. T. Banner. (7) Experimental Evaluation of Supersonic Wind Tunnel Performance with Solid and Porous Wall Test Sections Utilizing an Adjustable Supersonic Diffuser, R. V. DeLeo and J. Huerta. (8) Aerodynamic Characteristics of Bodies Immersed in Wake Flow, J. G. Ballinger and J. W. Parks. (9) An Experimental Investigation of the Use of Supersonic Driving Jets for Ejector Pumps, R. V. DeLeo, R. E. Rose, and R. S. Dart. (10) Performance Characteristics of a De-Iced Boundary Layer Control Total Temperature Probe, L. D. Huppert. (11) Studies Toward an Improved Radioactive Ionization Gage for Measurement of Extreme Altitude and Velocities, J. G. Ballinger and R. C. Horn. (12) Effects of Some Dimensional Variables on the Calibration Characteristics of Static Pressure Sources and Angle of Attack Sensors; Part I, Static Pressure Sources, M. J. Teigen; (13) Part II, Angle of Attack Sensors, M. J. Teigen. (14) Evaporative Film Cooling of a Hemisphere-Cylinder Model at M = 7 with Air Stagnation Temperatures up to 3000°R, R. Hermann, W. L. Melnik, and J. O. A. Stankevics. (15) Resumé of Present State-of-the-Art in the Measurement of Pressure in Modern High Speed Wind Tunnels, L. D. Huppert. (16) Experimental Investigation of Laminar Heat Transfer with Nonuniform Surface Temperatures at M = 4.3, D. G. De Coursin, R. E. Larson, and N. C. Helm. (17) Evaporative Film Cooling of a Mach Nunber 7 Laval Nozzle with Air Stagnation Temperatures up to 3000°R, R. Hermann, W. L. Melnik, and J. O. A. Stankevics. (18) Laminar, Transitional, and Turbulent Mass Transfer Cooling Experiments at Mach Numbers from 3 to 5, C. J. Scott, G. E. Anderson, and D. R. Elgin. (19) Integral Laminar Boundary Layer Solutions Using the Crocco Variables, C. J. Scott. (20) Experimental Investigations of Turbulent-Heat Transfer on the Base of a Two-Dimensional Body at M = 3, R. E. Larson and L. H. Zacho. (12) Mass Transfer Cooling Experiments on a Hemisphere at M = 5, G. E. Anderson, C. J. Scott, and D. R. Elgin. (22) Current Research in Hypersonic Gasdynamics at the Rosemount Aeronautical Laboratories, R. Hermann, W. L. Melnik, and J. O. A. Stankevics. (23) An Experimental Investigation for Evaluation of Droplet Size Distribution of Liquids when Sprayed from an Aircraft Store Model Submerged in a Free Jet Air Stream, R. V. DeLeo and R. E. Rose. (24) Pressure Recovery of a Shroud Diffuser on a Conical Inlet Model in a Free Jet Supersonic Wind Tunnel, R. Hermann, K. O. Thompson, and W. L. Melnik. (25) Bluff-Body Flame Stabilization at Low Pressures, C. C. Chang, G. Engholm, and L. H. Zacho. (26) The Hypersonic Facility of the Rosemount Aeronautical Laboratories: Design Considerations, Calibration and Performance Capability for Hypersonic Flight Studies, R. Hermann and J. O. A. Stankevics. (27) Afterbody Drag Reduction by Application of the Area Rule Accounting for Jet Exhaust, J. G. Ballinger and R. C. Horn.

COMPUTERS

Handbook of Automation, Computation, and Control; Vol. 2, Computers and Data Processing. Edited by Eugene M. Grabbe, Simon Ramo, and Dean E. Wooldridge. New York, John Wiley & Sons, Inc., 1959. 1041 pp., illus., diagrs., tables. $17.50.

Contents: (1) Computer Terminology and Symbols. (2) Programming and Coding. (3) Data Processing Operations. (4) Quantitative Characteristics of Data Processing Systems. (5) Equipment Description. (6) Facility Requirements. (7) Design of Business Systems. (8) Accounting Applications. (9) Inventory and Scheduling Applications. (10) Scientific and Engineering Applications. (11) Handling of Non-Numerical Information. (12) Digital Computer Fundamentals. (13) Techniques for Reliability. (14) Components and Basic Circuits. (15) Magnetic Core Circuits, I. L. Auerbach. (16) Transistor Circuits. (17) Logical Design. (18) Arithmetic and Control Elements. (19) Storage. (20) Input-Output Equipment for Digital Computers. (21) Analog Computation in Engineering. (22) Linear Electronic Computer Elements. (23) Nonlinear Electronic Computer Elements. (24) Analogs and Duals of Physical Systems. (25) Solution of Field Problems. (26) Noise and Statistical Techniques. (27) Mechanical Computer Elements. (28) Digital Techniques in Analog Computation. (29) Operational Digital Techniques. (30) Combined Analog-Digital Computing Systems. (31) Simple Turing Type Computers. Index.

DOCUMENTATION

SLA Loan Collection of Classification Schemes and Subject Heading Lists on Deposit at Western Reserve University as of November 1, 1958. Compiled by Bertha R. Barden and Barbara Denison. 4th Ed. New York, Special Libraries Assn., 1959. 51 pp. $2.50.

EDUCATION AND TRAINING

Engineering Education in Russia. Stephen P. Timoshenko. New York, McGraw-Hill Book Co., Inc., 1959. 47 pp., illus., tables. $2.75.

ELECTRONICS

Advances in Electronics and Electron Physics, Vol. 11. L. Marton, Editor. New York, Academic Press, Inc., 1959. 523 pp., illus., diagrs., tables. $15.

Contents: Recent Advances in Photoemission, P. Görlich. Parity Nonconservation in Weak Interactions, R. M. Sternheimer. Quantum Efficiency of Detectors for Visible and Infrared Radiation, R. C. Jones. Automatic Data Processing in the Physical Sciences, G. E. Barlow, J. A. Ovenstone, and F. F. Thonemann. Operational Amplifiers, R. L. Konigsberg. Radio Telemetering, H. B. Riblet. Electron Diffraction Structure Analysis and the Investigation of Semiconducting Materials, Z. G. Pinster. Secondary Electron Emission from Solids, O. Hachenberg and W. Brauer.

INSTRUMENTS

The Gyroscope; Theory and Applications. James B. Scarborough. New York, Interscience Publishers, Inc., 1958. 257 pp., illus., diagrs., tables. $6.50.

The aim of this book is to give a systematic and reasonably complete treatment of the mathematical and mechanical aspects of the gyroscope and its more important applications. Since it is concerned with fundamental principles, constructional details are not entered into except insofar as they may aid in clarifying these principles. Because the construction, mounting, and casing of modern gyroscopes sharply reduce friction of all kinds, this factor has been left out of consideration in the motion of the gyroscope itself. Vector methods are employed throughout the book, and a chapter on vector analysis is included for those readers having no prior knowledge of this branch of mathematics.

The author is Professor Emeritus of Mathematics, United States Naval Academy.

MATERIALS

Materials in Space Environment; Proceedings of the Fifth Sagamore Ordnance Materials Research Conference, Conducted at Sagamore Conference Center, Racquette Lake, N.Y., September 16–19, 1958. Co-Sponsored by Army Ballistic Missile Agency and Office of Ordnance Research, U.S. Army. Arranged by Syracuse University Research Institute. (MET 597-596.) Washington, Office of Technical Services, Dept. of Commerce, 1959. 366 pp., illus., diagrs., tables. $4.00. (PB-151900.)

Contents: Space Environment and Vehicle Requirements: Chemistry of the Moon, H. C. Urey. Overall Objectives and Outline of Problems, W. H. Steurer. Design Requirements of Space Vehicles, J. B. Cladis.

Physics of Space Vacuum and Effects on Materials: Physics of Space Vacuum and Effects on Materials, R. Herzog. The Effect of Atmosphere on Creep and Fatigue at Elevated Temperatures, M. R. Achter. High Vacuum Technique and Expected Effects on Materials, G. F. Vanderschmidt.

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Radiation and Radiation Effects in Outer Space: Nature of High Energy Radiation Encountered in Space, P. Meyer. Radiation Effects on Metals, E. Schmid. Radiation Effects on Non-Metals, H. R. Dvorak.

Meteorites and Cosmic Dust in Space: Meteoric Influx, F. L. Whipple and G. S. Hawkins. Meteorites and Cosmic Dust in Space, C. Tombaugh.

High Velocity Impact, W. S. Partridge. Effects of Meteorites on Materials and Simulation Testing. *Implications of Space Environment for Material Development* (Panel Discussion). Evolution of Space Travel, S. B. Batdorf.

Transactions of the Society of Rheology, Vol. 2, 1958. R. D. Andrews, Editor. New York. Interscience Publishers, Inc., 1959. 314 pp., illus., diagrs., tables. $8.00.

Contents: Presentation of the Bingham Medal to Clarence M. Zener, A. S. Nowick. Rheology of Peeling in a Newtonian Liquid, J. J. Bikerman and W. Yap. Dynamic Mechanical Properties of Fluorochemical Elastomers, K. E. Owens and C. A. Dahlquist. A Torsion Pendulum for Dynamic and Creep Measurements of Soft Viscoelastic Materials, D. J. Plazek, and M. N. Vrancken, and J. W. Berge. The Dynamic Mechanical Properties of a Model Filled System: Polyisobutylene-Glass Beads, R. F. Landel. A Photographic Study of Liquid Flow in a Roll Nip, J. C. Miller and R. R. Myers. On Relaxation Spectra in High Polymers, B. Albrecht and A. M. Freudenthal. Approximate Equations for Interconverting the Various Mechanical Properties of Linear Viscoelastic Materials, T. L. Smith. The Principles of Plastico-Dynamics, C. Torre. The Creep of Snow under Combined Stress, J. K. Landauer. Time Dependence of Mechanical Breakdown in Bundles of Fibers; 3: The Power Law Breakdown Rule, B. D. Coleman. The Tensile Strength of GR-S Elastomers, L. M. Epstein and R. P. Smith. Flow Behavior of Concentrated (Dilatant) Suspensions, A. B. Metzner and M. Whitlock. Flow of an Incompressible Visco-Plastic Layer on an Inclined Plane, P. R. Paslay and A. Slibar. The Capillary Experiment in Rheology, W. Philippoff and F. H. Gaskins. The Rheology of Various Solutions of Cellulose Derivatives, J. G. Brodnyan, F. H. Gaskins, W. Philippoff, and E. G. Lendrat. Abstracts of Additional Papers Presented at the Society of Rheology Meeting, November 7–9, 1957. Corrigenda: A Stochastic Process Model for Mechanical Breakdown, B. D. Coleman.

MECHANICS

Proceedings of the Fourth Midwestern Conference on Solid Mechanics, Held at the University of Texas, September 9–11, 1959. Austin, The University, 1959. 530 pp., illus., diagrs., tables. $12.50.

Contents: (1) Shell Theory, L. H. Donnell. (2) A Simplified Analysis of Circular Membranes Subjected to an Impulsive Loading Producing Large Plastic Deformations, D. Frederick. (3) The Dynamic Stress Field Due to an Extensional Dislocation, D. D. Ang and M. L. Williams. (4) A Shell Analysis of Compressor Blade Vibrations, F. Lane and S. Slutsky. (5) Fracture Arrest by Riveted Stiffeners, J. P. Romualdi and P. H. Sanders. (6) Further Stress Studies on a Square Plate With a Pressurized Central Circular Hole, W. F. Riley, A. J. Durelli, and P. S. Theocaris. (7) The Collapse Load of a Spherical Cap, P. G. Hodge, Jr. (8) General Small Deflection Theory of Elastic Bending and Buckling of Laminated Plates, L. G. Clark. (9) Elastic Stress Discontinuities in Ring Plates, J. N. Goodier and J. C. Wilhoit, Jr. (10) A Numerical Solution for Thin Conical Shells Under Asymmetrical Loads, G. A. Thurston. (11) Analysis of Thin Conical Shells Under Asymmetric Loading, R. Schile. (12) On Some Solutions for Large Deflections of Heated Strips and Plates, M. M. Chen and K. A. Foss. (13) On the Vibration of Thermally Stressed Plates, Y. Shulman. (14) Effect of Camber on the Thermal Stresses and Deflections of Cantilevered Plates, R. J. H. Bollard and A. R. Zak. (15) Optimum Design of Stiffened Panels and Sandwich Panels at Elevated Temperature, B. E. Gatewood and C. R. Jones. (16) The Redistribution of Hypersonic Thermal Loads Due to Structural Cross-Radiation, R. N. Baylor and F. C. Smith. (17) On the Elastic Impact of Short Cylindrical Rods on Long Cylindrical Rods, C. S. Barton and E. G. Volterra. (18) Longitudinal Plastic Waves in Long Rods of Strain-Rate Dependent Material, H. J. Plass, Jr., and N. M. Wang. (19) Impact of Cylinders of Different Areas, D. P. Clausing. (20) Further Transient Analysis of Stress Wave Propagation in Plates, A. Pytel and N. Davids. (21) A Comparison of Surface Strains to Average Strains in Longitudinal Elastic Wave Propagation, R. A. Graham and E. A. Ripperger. (22) Transverse Wave Propagation in a Solid, Elastic Mass Contained by an Infinitely Long, Rigid, Circular-Cylindrical Tank, J. H. Baltrukonis and W. G. Gottenberg. (23) Strain Rate Effects on Stress-Strain Characteristics of Aluminum and Copper, J. W. Turnbow and E. A. Ripperger. (24) Natural Frequencies of Vibration of Simply Supported Sandwich Beams, W. R. Kimel, M. E. Raville, P. G. Kirmser, and M. P. Patel. (25) Bending Waves in Free-Free Beams, S. S. Kuo. (26) Damping of Flexural Vibrations by Alternate Visco-Elastic and Elastic Layers, E. E. Ungar and D. Ross. (27) On the Transient Behavior of a System Under a Random Disturbance, J. L. Bogdanoff and J. E. Goldberg. (28) A Generalization of the Finite Integral Transform Technique and Tables of Special Cases, S. Kaplan and G. Sonnemann. (29) Spin Dynamics of a Thrusting Rocket in Vacuum, H. I. Leon.

POWER PLANTS

Advanced Propulsion Systems; Proceedings of a Symposium Held in Los Angeles, December 11–13, 1957. Edited by Morton Alperin and George P. Sutton. New York, Pergamon Press, Inc., 1959. 237 pp., illus., diagrs., tables. $6.00.

In this volume many new and imaginative concepts of physical propulsion, power sources, new propellants, hardware, and human hazards of space flight are explored in the light of present knowledge and scientifically predicated conjecture. The papers contained therein include the unclassified and declassified contributions of leading scientists to the First Advanced Propulsion Systems Symposium sponsored by the AFOSR and by the Rocketdyne Division, North American Aviation, Inc.

Contents: Ion Propulsion Systems, S. Naiditch. Experimental Studies on the Thrust from a Continuous Plasma Jet, G. Cann, A. Ducati, and V. Blackman. The Ion Rocket Engine, R. H. Boden. Comparison of Propulsion Systems: Solar Heating, Arc-Thermodynamics, and Arc-Magnetohydrodynamics, K. A. Ehricke. Thrust from Plasma, W. H. Bostick. Potential Aircraft Applications of Closed Gas Cycle Nuclear Power Plants, R. D. Buhler and P. J. Gingo. Speculation About Future Trends in Lightweight Electric Equipment, R. A. Koehler. Direct Power Conversion: Part 1, General Comments, J. H. Huth; Part 2, The Fission-Electric Reactor, G. Safonov. Electrostatic Generators, A. J. Gale. Magnetohydrodynamic Generators and Propulsive Devices, R. J. Rosa. The Liquid Propellant Status Quo, J. F. Tormey. Ozone—Fluorine, E. N. Hall. The Use of Metals and Metal Hydrides in Rocket and Jet Propulsion, J. M. Carter. Human Hazards of Space Flight, H. J. Stewart. Stabilized Free Radicals, J. L. Jackson. Research on Free Radicals as Rocket Propellants, G. Moe and D. L. Armstrong. System Considerations Affecting New Propulsion Applications, A. F. Donovan.

RESEARCH

Applications of Manned Stratospheric Laboratories; Minutes of Sessions Held at the 27th Annual Meeting of the Institute of the Aeronautical Sciences at New York, 29 January 1959. Compiled and Edited for the ONR. Silver Spring, Md., Vitro Laboratories, 1959. 173 pp., illus., diagrs., tables.

Contents: Session I. Introductory Remarks, D. H. Menzel. Requirements for High Resolution Photography of Planets, G. H. de Vaucouleurs. Infra-Red and Ultra-Violet Measurements at High Altitude, J. Balmont. Proposed Observations of the Martian Atmosphere, M. D. Ross. Geophysical Researches of Stratospheric Laboratory, W. O. Roberts and G. A. Newkirk, Jr. Measurement of Atmospheric Dispersion and Vertical Motion, H. T. Mantis. Observation of Severe Storms from Above, B. Vonnegut. Panel Discussion.

Session II. Introductory Remarks, N. L. Barr. Training in Preparation for Manhigh I, J. Kittinger. Cosmic Ray Detection by Visual Scintillations, H. Yagoda. The Balloon-Borne Capsule as a Space Flight Trainer, E. E. Beson. Infra-Red Spectroscopy from Balloons and the Possibility of Some Observations on the Biosphere, D. M. Gates. The Strato-Laboratory as a Systems Testing Platform, J. R. Smith. Panel Discussion.

Operations Research; Methods and Problems. Maurice Sasieni, Arthur Yaspan, and Lawrence Friedman. New York, John Wiley & Sons, Inc., 1959. 316 pp., diagrs., tables. $10.25.

The subject matter proper of this book begins with a brief survey of the elements of probability theory, including the notions of probability of an event, random variable, probability distribution, and conditional probability distribution. This material is basic for an understanding of some of the remaining chapters, and should serve as a good review even for those readers who are already familiar with probability. The succeeding chapter discusses sampling, and gives an introduction to the Monte Carlo method of simulated sampling. Chapters 4–10 present various problem areas which have gradually taken distinct shape in operations research; in order, they are inventory, replacement, waiting lines, competitive strategies, allocation, sequencing, and dynamic programing.

Operations Research is addressed to readers who have a working knowledge of the differential and integral calculus and features a problem-centered approach to its subject. Although a great deal of elegant mathematics usually appears in operations research literature, the authors stress that far more problems can be solved by the intelligent application of simple arithmetic, and, consequently, their examples are stated in such a way that a mathematical model can be written down by the application of elementary reasoning.

ROCKETS

Introduction to Rocket Technology. V. I. Feodosiev and G. B. Siniarev. Transl. from the Russian by S. N. Samburoff. New York, Academic Press, Inc., 1959. 344 pp., illus., diagrs., tables. $9.50.

In this textbook the authors have undertaken the task of introducing the reader to the general subject of rocket technology without demanding of him extensive preparation, especially in the sophisticated fields of aero-gas-dynamics and thermodynamics; they consider that a general background in the elements of physics, chemistry, and the fundamentals of higher mathematics is quite sufficient for adequate understanding. Nor do they touch upon the military uses of rockets or the many specialized subjects of rocket technology, having an independent character, such as radio control, guidance, and telemetering.

S. N. Samburoff is presently with the Applied Physics Laboratory, The Johns Hopkins University.

Contents: (1) The Basic Relationships in the Theory of Reactive Motion. (2) Types of Jet Propelled Aircraft and Their Basic Construction. (3) Types of Reaction Motors, Their Construction and Operational Characteristics. (4) Rocket Motor Fuels. (5) The Processes in the Combustion Chamber of a Rocket Motor. (6) Flow of the Combustion Products Through the Nozzle of a Rocket Motor. (7) Forces and Moments Acting on the Rocket in Flight. (8) Rocket Flight Trajectory. (9) The Basic Principles of Stabilization and Steering. (10) Ground Equipment and Launching Devices. Index.

SAFETY

Aircraft Accidents Involving Maintenance, 1 January–31 December, 1958. Norfolk, Va., Maintenance and Material Dept., U.S. Naval Aviation Safety Center, September, 1959. 45 pp., illus., tables.

The study includes all aircraft accidents and incidents in which a contributing cause was maintenance personnel error. A breakdown of accidents/incidents by aircraft systems and a brief description of the occurrences are presented for each model of aircraft.

SCIENCE

Science and Technology in Contemporary War. Georgy I. Pokrovsky. Transl. and Annotated by Raymond L. Garthoff. New York, Frederick A. Praeger, 1959. 180 pp., diagrs. $4.50.

The present volume is an unabridged translation of the key writings of Major Gen. Georgy I. Pokrovsky, Soviet Army Officer, nuclear physicist, professor of military engineering, and member of the Soviet Interdepartmental Commission for Interplanetary Communications. Frequent reference is made to missile and aircraft development.

WIND TUNNELS

Aeroballistic Research Facilities. (NOLR 1233.) White Oak, Silver Spring, Md., U.S. Naval Ordnance Laboratory, 1959. 72 pp., illus., diagrs.

Descriptions and operating characteristics of the White Oak wind tunnel and ballistic range facilities and auxiliary equipment.

Subsonic Wind Tunnels. (General Description Report No. 721–74.) Pasadena, Calif., Aerolab Development Co., Inc., 1959. 27 pp., illus., diagrs., tables.

In addition to a general description of the physical features of the Aerolab subsonic tunnel, there are data on the construction, performance, and utilization of the four general configurations and three basic sizes offered by the company. Various support equipment, drive motors, and starters are also described.

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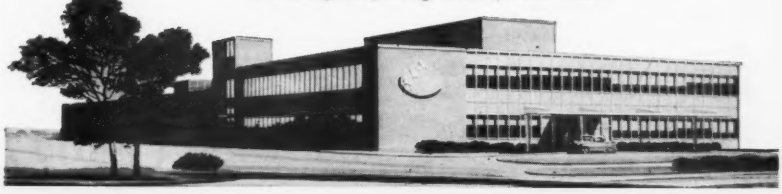

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